UPDATE OF NETWORK PLANNER RESULTS USING 2012 DATA FOR GREATER ACCRA AND NORTHERN REGION WITH SPECIAL EMPHASIS ON THE EFFECTS OF INTER-HOUSEHOLD DISTANCE

By

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DECLARATION

I hereby declare that this thesis is the result of my own original research work undertaken under the supervision of the undersigned, that all works consulted have been referenced and that no part of the thesis has been presented for another degree in this University or elsewhere.

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CERTIFICATION

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(Supervisor) Signature Date

Dr. S.M Sackey ……………………. …………………

(Head of Department) Signature Date

DEDICATION

This work is dedicated to the glory of

God the Father, God the

Son and God the

Holy Spirit.

ACKNOWLEDGEMENT

I take this opportunity to express my profound gratitude to my supervisor, the late Professor Abeeku Brew-Hammond whose vision and foresight has inspired this work and also for entrusting me to undertake this important but challenging assignment. I am highly indebted to him for providing guidance, direction, insightful comments and support throughout the period of this work.

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ABSTRACT

The Government has over the last few decades intended to increase energy access in Ghana but in spite of the good intentions, existing plans, policies and programmes have not delivered the best results.

This thesis work seeks to use and support the GIS-based programme model for implementing the policies and Plans to increase Energy Access plans in Ghana.

It has been shown that the penetration rate has a major influence on the total cost of all the electrification options as well as the connection cost per household. A lower penetration rate tends to lower the total cost of all the electrification whereas the connection cost per households increases since the same general infrastructural cost is pooled among fewer number of households.

The results also indicates that reducing the mean inter-household distance (MID) tend to shift more communities to be grid compatible since the total cost per household will be lower and hence lower cost for grid technology. It shows that the MID is the deterministic factor of the required length of LV grid lines for the connecting households.

It can also be pointed out that lowering the diesel fuel cost per litre results in a higher percentage of diesel mini-grid compatible communities. Diesel cost also affects the other electrification technologies.

The Network Planner (NP) is a great tool that has helped in prioritizing areas for increased energy access by proposing the most cost-effective electrification option within a specified time horizon.

In terms of social implication the NP can be used as a supporting tool for the extension of electricity access to communities that are not electrified.

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ABBREVIATIONS

EAD	Energy Access Data
ECG	Electricity Company of Ghana
ECOWAS	Economic Community of West African States
GIS	Geographic Information System
GIS-EAP	Geographic Information Systems Energy Access Project
GPRS	Ghana Poverty Reduction Strategy
GW	Gigawatt
GWh	Gigawatt-hour
HH	Household
Inter-HH	Inter-Household
kWh	kilowatt-hour
LCOE	Levelised Cost of Electrification
LPG	Liquefied Petroleum Gas
LV	Low Voltage
MDGs	Millennium Development Goals
MID	Mean inter-household distance
LEAP	Long range Energy Alternatives Planning
MV	Medium Voltage
MV-Line	Medium Voltage Line
MVmax	Maximum Medium Voltage
NED	Northern Electricity Department
NES	National Electrification Scheme
NP	Network Planner
PR	Penetration Rates

PV	Photovoltaic
SHS	Solar Home System
SNEP	Strategic National Energy Plan
UNDP	United Nations Development Programme
VALCO	Volta Aluminum Company
VRA	Volta River Authority

CHAPTER ONE

INTRODUCTION

1.1 Background

One of the significant drivers of socio-economic development of a country is the country's access to energy. The importance of access to electricity compared to other forms of energy is so enormous. For instance, its contribution to health, education, agriculture and environmental sustainability has facilitated human development. Moreover and particularly in the rural areas, access to electricity has helped to reduce time and efforts spent (especially by women and children) in the collection of other fuels such as firewood and kerosene for lighting; and has also reduced rural to urban migration in search for jobs and modern facilities. In addition, potential benefits of electricity in rural areas include crop irrigation, agro-processing and preservation of farm produce **[Kemausuor et al 2010].**

For an effective assessment of energy access in Ghana, Geographic Information System (GIS) planning tool was thought necessary for a timely analysis and review of population and service distribution (such as improved heating/drying systems, cook stoves, Liquefied Petroleum Gas (LPG) distribution and mechanical power), grid-extension, mini-grid and off-grid plans. This method is useful because it seeks to provide data and analysis to enable policy makers, private sector and development partners like European Union Energy Initiative (EUEI), United Nations Development Programme (UNDP) and the World Bank as well as regional organizations such as the Economic Community of West African States (ECOWAS) to determine the additional measures or adaptations that will be needed to achieve the energy access targets of Ghana.

1.2 Justification

Due to high cost of investment, policy makers and planners need tools to understand the total cost of electrification for the un-electrified communities in each region. The cost of electrification differs widely across the ten regions due to remoteness (distance from existing electricity grid network), size (land area), the number of non-electrified communities coupled with large population size and the projected electricity demand.

The scattered pattern of settlement in Northern Ghana and the existence of many non-electrified communities amply suffice the relatively high electrification cost compared to other regions especially Greater Accra region which has the reverse characteristics. The availability of such electrification cost ranges provide a useful guide to the financing mechanisms or investments required either from private sectors or the government to achieve a certain level of penetration rate and eventually universal access (100%) by 2020.

This thesis seeks to do a comparative analysis of two regions using an updated database based on the effect of inter-household distance. For this sensitivity analysis, the Northern and Greater Accra regions were considered. The motivation for this selection was because of the variability in population densities of the regions, with Northern region having the least population density and Greater Accra having the most population density.

Results and recommendations from the this thesis will also contribute to the body of knowledge in the area of electricity expansion planning, and form a reference point to researchers, planners, and other stakeholders

1.3 Objectives

The main Objective of this thesis is to investigate the impacts of Inter-Household Distance on the cost of electrification expansion in Ghana.

The specific objectives are listed as follows:

1Run Network Planner using dummy or proxy data to get familiar with the software;

2. Comparative analysis using the 2010 results and updated 2012 databases for both Greater Accra and Northern Regions;

3. Undertake sensitivity analysis to explore the effect of Inter-Household Distance for the two regions using classical experiment (changing one parameter at a time).

1.4 Scope of Work and Thesis Organization

The main scope of the research work will be investigated and presented in the following chapters. Chapter 1 will lay a foundation for the network planner. Chapter 2 presents an intensive literature review and background studies on energy access and other electrification planning tools. Chapter 3 discusses the methodology for the thesis work. The analysis will be carried out by using results from the updated 2012 analysis and comparing it with the base year (2010). Chapter 4 deals with the results obtained from the sensitivity analysis carried out in this work, and some assumptions will be made at the various penetration rates, current cost of diesel and at various specific inter-households distances.

Conclusions and recommendations are presented in chapter 5. The organization of this thesis is shown diagrammatically in figure 1.

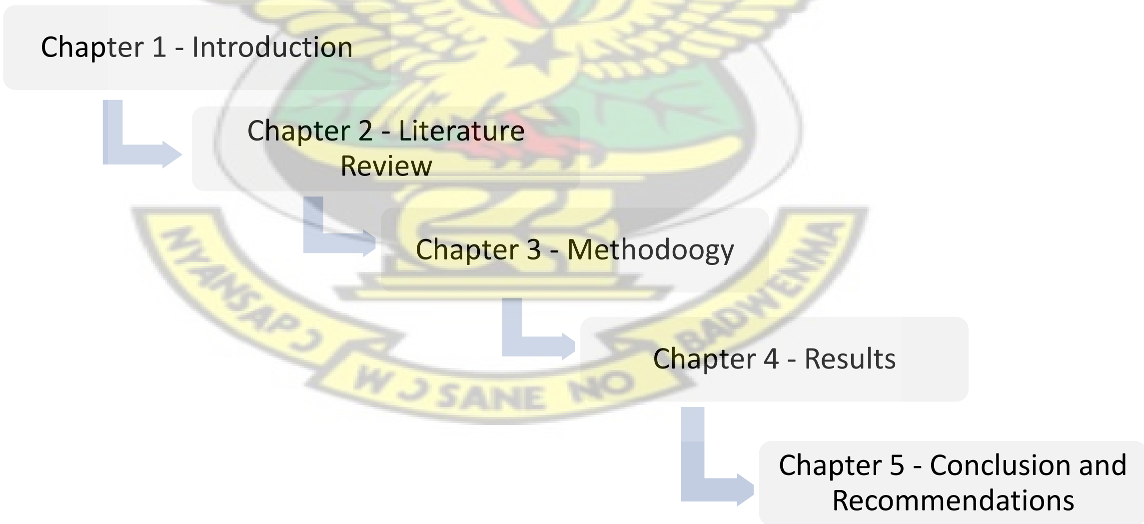

Figure 1.1: Organization of Thesis

CHAPTER TWO

LITERATURE REVIEW

2.1 Energy Access

Over the next ten years, countries in sub-Saharan Africa are expected to increase their share of energy generation and utilization to meet economic growth. Despite the existence of enormous energy sources in this region, electrification rates remain low. Rural electrification rates of around 15% and national rates in the 30–40% range have become one of the most restrictive bottlenecks to development. In addition, population growth is exceeding connection rates in most countries, which does not augur well for raising electrification rates (Haanyika, 2006).

Given current conditions and financial constraints, energy planning in Sub-Saharan Africa should center on self-sufficient and environmentally sound energy policies that take full advantage of the impact of investment and support economic growth (Weisser, 2004). Strategies that lower electrification costs, particularly household connection costs, are crucial to the economic future of the region.

In spite of the widespread unanimity that, the provision of affordable, reliable, and socially conventional energy services are prerequisites for achieving the Millennium Development Goals (MDGs) [Brew Hammond et al], inadequate access to energy services continues to be a major challenge to sustainable development.

The global energy sector faces a number of challenges including lack of access to the electric grid at reasonable prices, volatile oil price markets, high initial cost of renewable energy technologies, a general lack of cognizance of the scale of renewable energy resources, increased greenhouse gas emissions, etc. [IEA, 2002; Sawin; UNDP,2004].

Although most of the challenges facing developing countries are comparable to those in the industrialized countries [Sawin, 2004], delicate economies, growing population, low investments and poor energy infrastructure, among others, compounds the challenges of developing countries.

Ghana's energy sector policy objectives of ensuring reliable, adequate and cost-effective supply of high quality energy services for households, industries, agriculture and transport are consistent with the outlined prerequisites for achieving the MDGs [EC, 2004]. Ghana has also subscribed to the energy access targets of the 'Economic Community of West African States (ECOWAS) White Paper for a Regional Policy' geared towards Increasing Access to Energy Services.

The ECOWAS White Paper was put forward to enable at least half the population of the West African sub-region have access to modern energy services by the year 2015 [ECOWAS, 2005]. But, existing policies and plans have not delivered effective results to enable the population derive the maximum benefits of increased access to energy services. There is also a lack of data to determine whether current energy policies and plans will achieve the targets for energy access as established in the government's policy documents, ECOWAS White Paper and the MDGs. Policies and plans to provide the enabling environment for enhancement in energy access are hardly appraised and hence the need for a continuous research especially for monitoring and evaluation purposes. Nearly 50% of the Ghanaian population who do not have access to grid-electricity and about 90% who do not have access to liquefied petroleum gas (LPG) for cooking rely on firewood and charcoal [GSS,2005; UNDP Ghana, 2004]. Their hope is to improve their socio-economic well-being by gaining access to modern forms of energy.

2.2 Trends in Ghana's energy sector

Developments in the energy sector of Ghana with particular emphasis on energy at the household level, namely, electricity, LPG, kerosene, and renewable energy including woodfuels (firewood and charcoal) is considered in this section

2.2.1 Electricity:

In 2012, the total grid electricity generated in the country was 12,164 Gigawatt-hours (GWh) and for 2013, the total electricity needed for the country would be in the range of 13,667 - 15,794 GWh. Higher than expected average annual precipitation is expected this year – 2013, according to the Ghana Meteorological Agency (GMA) [GMET, 2013]. Higher inflows into the hydropower reservoir would increase the overall power generation to compensate for the inadequate or delayed gas supply. The low-side represents relatively low supplies due to comparatively high cost of energy as a result of lower than expected flow of gas for power generation. The high-side covers VALCO operating at two-to-three potlines. It is anticipated that between 13,459 - 16,121 GWh could be supplied by the public utilities through the national grid depending upon sufficient fuel supply for power generation. The low-side represents relatively high cost of fuel or inadequate gas supply.

In 2012, Ghana's peak load on the transmission grid was 1,729 Megawatts (MW) and the total peak on the overall grid system was 1,871 MW. For 2013, Ghana's peak load and the total system peak on the grid transmission system would be about 1,800 MW and 1,900 MW respectively [EC, 2013]. For VALCO to be operating between 3-4 potlines, the Ghana's and the system's peak would increase to 1,980 MW and 2,500 MW respectively.

Except for the restrictions placed on VALCO operations, there should be no significant shortfall in electricity supply to meet demand provided there is sufficient supply of fuel for power generation. In summary, installed capacity would not be the challenge but fuel supply is the constraint [EC, 2013].

Shortfall in fuel supply would compel the utilities to continue to quota power by resorting to load-shedding. Large consumers however meet their electricity supply shortfall by private and back-up generation at the point of use, or cut down or suspend operations during load-shedding hours. Higher than expected average annual precipitation is expected this year – 2013, according to the Ghana Meteorological Agency (GMA). Higher inflows into the hydropower reservoir would improve the overall power generation to offset inadequate or delayed gas supply.

In 2011, the total grid electricity generated in the country was 10,167 Gigawatt-hour (GWh). The Ghana load at peak on the transmission grid was 1,665 Megawatts (MW) and the grid system peak was 1,745 MW.

Between 1989 and 1990, the government committed itself to raise access to electricity for all parts of the country over a 30-year period under the national electrification scheme (NES). The programme established projects that are driven towards the provision of electricity access to the northern parts of the country, which then un-electrified. In 1990, the VRA rehabilitated and re-commissioned the Tema Diesel Generating Station which has a capacity of providing supplementary generation of 30 MW thereby raising the total capacity of electrical power to about 1,102 MW.

Between 1990 and 2001, electricity consumption grew from 4,457 GWh to 6,033 GWh at an average rate of 9.42% per annum, excluding the Volta Aluminum Company (VALCO), whose Aluminum smelter at Tema used up around 40% of total electricity supply in the mid-1990s [EC, 2004]. The increase in consumption, as compared with population growth of 2.67%, was due to a remarkable increase in electricity access from 28% in 1988, 32% in 1992 and 43.7% in 2000 [EC; 2004, Akuffo FO; 2005; MOE; 2006]. Electricity access rate of Ghana was estimated to be 54% in 2007 [EC; 2004] and 55% in 2008 [World Bank; 2009], making Ghana the third highest in sub-Saharan Africa, after Mauritius and South Africa.

Despite the increased access to electricity nation-wide, there exists a big disproportion in access between the urban and rural areas as reported by the Ghana Statistical Service [GSS; 2007]. This contrast between rural and urban areas is revealed in a more upsetting mode in 2006, Ghana experienced a power crisis due to low electricity generation capacity. The crisis prompted the government and VRA to review their long-term electricity policy in terms of the electricity generation mix required for national investments and long term needs [NDPC; 2007; Sackey T; 2007]. Momentous investments have since been made in thermal plants and system upgrading with the completion of VRA's 126 MW Thermal 1 Project. Several independent power projects are also at various stages of advancement, all at Tema most of which have been completed. The 400 MW Bui Power plant by the Chinese (Sino Hydro) has also just been completed. There is likelihood of work starting soon on the Western rivers. The figure 2.1 shows the trend in electricity generation in Ghana.

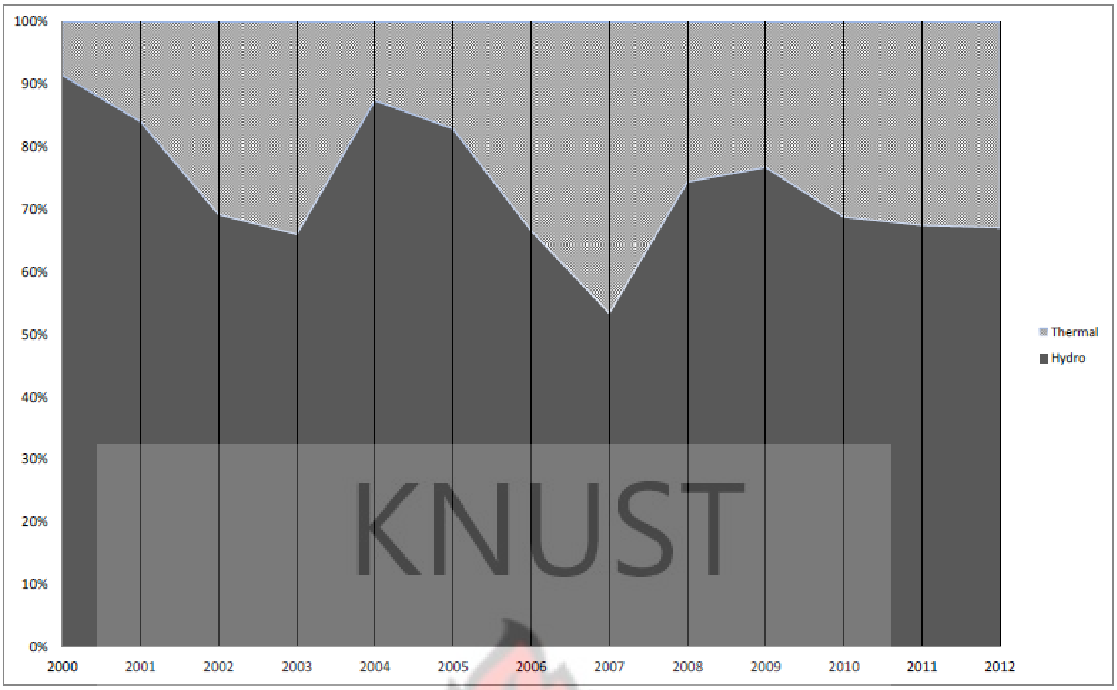

Figure 2.1: Trend in Electricity Generation in Ghana.

Source: 2013 Energy Outlook for Ghana from EC website

2.2.2 Petroleum

Ghana bought Brent crude at an average price of $113 per barrel in 2012. Thus average price is expected to be lower in 2013 by 3-4%. [EC; 2012]

For 2013, it is estimated that the total crude oil and imported products required would increase to 3.0 - 3.5 million tonnes from 2.9 million tonnes in 2012, in order to meet optimal refinery operations and imported products for local consumption.

Crude oil required for refinery operations would vary from 1.6 - 1.9 million tonnes (12 - 13 million barrels) during the year, depending upon the availability of the Tema Oil Refinery and its auxiliary units. The remaining 1.4 - 1.6 million tonnes of products would have to be imported.

For LPG, the total national requirement could likely be in the range of 250,000-300,000 tonnes for the year due to the growing demand, particularly as transport fuel. However, limited nation-wide storage capacity and the insufficient revenues generated from its sales due to cross-subsidization could continue to constrain supply to 220,000 - 250,000 tonnes range in 2013.

The breakdown of the total petroleum products required would be as follows:

Table 2.1: Total petroleum product required

Product	National Supply Requirement	Export Included
	Tonnes	
Total Gasoline	850,000 – 970,000	1,000,000
Total Diesel	1,600,000 – 1,700,000	1,830,000
Kerosene/ATK	200,000 – 230,000	300,000
LPG	250,000 – 300,000	350,000
Total	**3,000,000 – 3,200,000**	**3,500,000**

Crude oil production from the Jubilee field increased from an annual average of about 73,000 barrels per day in 2011 to an annual average of 81,000 barrels per day in 2012, and yet still short of the target of 120,000 barrels per day projected by the field operators for last year. Production however ramped up to 100,000 barrels per day during the last quarter of 2012.

With technical challenges almost resolved, according to Tullow Oil, the operator, production is likely to range between 100,000 - 120,000 barrels per day in 2013.

2.2.3 Liquefied petroleum gas (LPG)

LPG in Ghana is used as a fuel for domestic consumption and transport. In 1990, the Government of Ghana launched a National LPG Programme under which the Tema Oil Refinery was to be modernized and a substantial LPG campaign was implemented. This presented the opportunity to promote LPG as an alternative energy to charcoal and firewood. The promotion targeted urban households, public institutions requiring mass catering facilities and the informal commercial sector including small-scale food vendors [UNDP; 2004].

Government's initiative were prolific since the consumption of LPG doubled in 1992, and by 2004 domestic consumption was over 60,000 tonnes/year which was estimated to be about ten times higher than the quantities consumed before the promotional programme was launched [UNDP Ghana, 2004]. Though the LPG drive was successful, it is perceived that patronage was skewed in favour of urban dwellers. [Denton F.; 2006] contends that given the high consumption of charcoal in urban areas, concentration in the urban areas is a positive step to reverse the rates of deforestation and thus decrease demand for charcoal and woodfuel.

From the 6% of households in 2004, and about 9% in 2005 using LPG as their primary source of fuel for cooking, 70% resided in Greater Accra and Ashanti regions. In Accra, the Ghana's capital, about 22.7% in 2004 and about 30.4% in 2005 of households used LPG [GSS, 2007; MOE, 2006]. Urban access to LPG was estimated to be 17.2% and in divergence, LPG in rural areas accounted for about 1.2% of total national consumption. A current study found that only about 19% of households in the upper income quintile in Ghana have access to LPG, reducing to about 2% in the lowest income bracket group [Prasag, 2008].

As of December 2003, there were 98 LPG filling stations in Ghana, 64 of which were situated in the Greater Accra region and only one station each in the Upper East and Upper West regions. In 2004, the Government with financial backing from the United Nations Development Programme (UNDP) under its Rural LPG Challenge programme re-launched the LPG campaign programme to focus on the Northern regions of Ghana [Denton F., 2006]. A national survey conducted by the authors in early 2011 indicates that there are currently more than 200 LPG filling stations in the country.

In the year 2007, the Tema Oil Refinery exported about 9616 tonnes of LPG and imported about 47,226 tonnes to meet local demand [EC; 2007].

Some authors have testified that one of the key constraints to the initial promotion of LPG was the relatively high upfront cost compared to that of woodfuel with the cost of the cylinder contributing significantly to the high cost [UNDP Ghana; 2004].

2.2.4 Charcoal

Average prices of charcoal in Ghana rose from GH¢9 per mini bag and GH¢15 per maxi bag in 2011 to GH¢11 per mini bag and GH¢18 per maxi bag in 2012. The high-price regions for 2012 were Western and Central. The low-price regions were Ashanti, Brong-Ahafo and Northern, the latter also saw a drop in average mini-bag charcoal price.

Average prices however dropped in Greater Accra for maxi bag and in Northern Region for mini bag. Average charcoal price for mini-bag more than doubled in Upper East and West Regions. Eastern and Western Regions also experienced significant charcoal price increment.

It is estimated that average charcoal price in 2013 could range between 20 - 25% over 2012 average price nationwide due to general rise in LPG price, an alternative but cleaner cooking fuel. Increases could go up between 30 - 35% on the average in the southern sector due to LPG supply shortages and further expected rise in transportation and labour costs. [EC, 2013]

2.2.5 Renewable energy sources

The African continent is endowed with abundant renewable energy resources [Deichimann; 2011, Bugaje; 2006] and Ghana is no exception. Ghana's renewable energy resources that have been extensively studied as potential sources for energy production and utilization are bioenergy (particularly, solid biomass and biogas), solar, wind and small hydro.

2.3 Policy framework for increasing energy access

2.3 1 Policies, plans and programmes up to 2000

The first attempt to develop a modern legal framework for the energy industry in Ghana was in 1920, when the Electricity Supply Ordinance was passed [Botchway; 2000]. The ordinance provided for private generation, regulation of diesel-based power and the inspection of generation activities by government officials. Under the Ordinance the Electricity Department was established as the state regulatory agency. However, due to lack of private sector involvement in the industry, it became the sole power utility responsible for the generation, transmission and distribution of power. Though the idea of the Volta River Scheme originated as far back as 1915 in the colonial era, it was the first Government of Ghana that initiated the Volta River Project and saw to its completion [Botchway; 2000].

An aspiring rural electrification programme was embarked upon in 1972, which had the objective of increasing electricity access for the rural population. It was pursued within what is understood from some authors as a comprehensive rural development policy [Botchway; 2000].

The NES was introduced in 1989 / 1990 in which the Government of Ghana committed the country to increase electricity access to all communities with population above 500 by the year 2020 [EC, 2004, 2005]. The NES was planned to proceed in six 5-year phases over the period 1990 – 2020. The electrification of the several thousand villages in the country has been assumed to be by grid extension, with community participation under the self-help electrification program (SHEP). Challenges envisaged within this programme include: low density of potential consumers of rural areas (especially in Northern Ghana); low income levels in rural communities; significant distances required for medium-voltage lines; the costs of medium and low-voltage; cost of transformers, and service drops. In the 1990s concerns arising out of the escalating consumption of woodfuels resulted in several bioenergy programmes including the Improved Charcoal Cookstove Project, Improved Charcoal making Project, Biogas Project, and National LPG Promotion Programme.

These programmes and projects were inter alia aimed at reversing the rapid environmental and ecological damage, as evidenced by perceptibly high rates of deforestation and desertification as well as the worsening effects of global warming and other atmospheric pollutants from the inefficient production and use of wood fuel [Abakah. Oxford 1993]. The immediate objective of the national policy on wood fuel production and utilization was to ensure sustainable production, marketing and consumption of wood fuels. A key recommendation of the policy was that government should support the promotion and development of sustainable management of the country's natural forests and woodlands for sustainable supply of wood including wood fuels [EC; 2006].

2.3.2 Policies, plans and programmes after 2000

Between 2000 and 2005, government adopted a formal energy policy, which recognized the provision of adequate energy supply for meeting development objectives of poverty reduction and economic growth, emphasizing private sector participation to overcome funding constraints. The overall Government policy was aimed at facilitating a “Golden Age of Business” and stressed on improved availability, accessibility and affordability with special focus on rural areas [NDPC; 2007]. The Ghana poverty reduction strategy (GPRS) documentation also emphasized reliable supply of high quality energy to boost industrial development and cost recovery pricing while protecting the poor, continuation of rural electrification, promotion of energy efficiency and renewable energy. The introduction of the GPRS brought new policy directions to expand the use of renewable energy in rural electrification programmes in Ghana.

In 2006, the strategic national energy plan (SNEP) was prepared by the Energy Commission. The SNEP took a complete look at the available energy resources of the country and how to tap them economically and in timely fashion to ensure a secured and adequate energy supply for sustainable economic growth up to 2020[EC; 2006]. The goal of SNEP was to contribute to the development of a sound energy market that would offer sufficient, feasible and efficient energy services for Ghana’s economic development. This is to be achieved through the formulation of a comprehensive plan that would identify the optimal path for the development, utilization and efficient management of energy resources obtainable to the country. The SNEP identified key energy sources for long-term development and sustainability of electricity supply to include hydro-power, gas-powered thermal plant, renewables (such as wind, solar energy and biomass) and nuclear energy technologies.

Unfortunately, the SNEP was not adopted formally by the Government and one of the challenges for the energy sector today is how to redress this situation and make the SNEP a binding policy document.

2.4 Key issues and options for increasing energy access

This section is organised around the following three broad themes:

a) Electricity for all by 2020;

b) LPG/improved cooking systems for all by 2015;

c) More productive uses of rural/renewable energy.

2.4 1 Electricity for all by 2020

Ghana currently ranks third highest in sub-Saharan Africa, after Mauritius and South Africa, as far as access to electricity is concerned. Mauritius has already achieved universal electrification and South Africa is aiming to do the same. Current rates of electrification in Ghana may not lead to full electrification by 2020, as set originally in the NES and reaffirmed by the current Government.

Alternative Energy Africa estimates Ghana's rate of increase in demand for electricity at 10 – 15% per annum over the last two decades. [Alternative Energy Africa; 2009]. Thus an important consideration is to match the growth rate of electricity demand with adequate supply at reasonable prices. Though progress has been made towards achieving the goal of reliable and adequate supply of electricity at reasonable prices, much effort is needed to improve already existing installed capacity, and manage generation and distribution losses as well as reduce costs and prices to realistic levels. This raises major questions on both the supply and demand sides of the electricity supply chain.

On the supply side, the growing demand for energy and the constraints in supply as well as inadequate financing were the key factors that initiated reforms in the energy sector. In the case of the power sector, the on-going reform / restructuring programme has proceeded in fits and bursts over the last 15 years. If the sector is to succeed in playing its role towards meeting the 2020 universal access target, a renewed stimulus will be required in the implementation of the reform / restructuring programme and more dynamism will be needed in the distribution as well as generation sides of the industry. The generation side of the industry could also benefit from the introduction of more dynamism to ensure that adequate electricity supply is guaranteed.

The ambition of Ghana's founding fathers to produce cheap electricity has not been sustained due to several challenges including the lack of a combination of coherent policies among others to consolidate, improve and diversify sources of electricity supply in Ghana [EC; 2006]. Contrary to this ambition, electricity prices have been on the rise and several mechanisms, including regional power pooling, are being put in place to reduce cost of electricity and improve reliability.

A process towards reforming the power sector and driving more dynamism into the industry with a good eye on the ECOWAS regional electricity market could well be the approach that might deliver results.

2.4.2 LPG / improved cooking systems for all by 2015

As earlier indicated, about 9% of Ghana's population in 2005 used LPG as their main energy source for cooking. The corresponding LPG access rates for rural areas, urban areas and Accra are 2%, 17% and 30%, respectively. With Ghana's urban population predicted to approach 60% by 2030 it should be possible to take advantage of the relative ease of LPG uptake in urban areas and double LPG access from the 2005 rate of 9% to something much closer to 20%, with the rest of population using improved woodfuel-based cooking services, by 2015.

2.4.3 More productive uses of rural / renewable energy

It has been argued elsewhere that efforts which succeed in integrating productive uses and income generation activities into energy access initiatives, whether based on conventional fuels or renewable energy, may well turn out to be the deciding factor if the vision of energy for all in sub-Saharan Africa is to become a reality in the foreseeable future [Brew Hammond et al].

A recent study in Northern Ghana concluded that the low contribution of energy towards rural development is to a great degree driven by an energy policy that inhibits the delivery and use of modern energy sources in rural Ghana [Kankan; 2009]. Achieving an energy future that has greater relevance to rural development will therefore require a mix of policy tools that enhances the delivery and use of modern energy systems in rural communities in the country. The extent to which Ghana is able to successfully frontier energy access initiatives with implanted linkages to productive uses / income generation may therefore help to make the difference, whether or not universal access to modern energy services will be achieved by 2020.

The challenge of integrating strong productive use elements in energy access initiatives in general and renewable energy drives in particular cannot be underestimated. But there is evidence to suggest that with some vigilant thinking and innovative programme design, this should be practical with tangible results for all to see. For instance, an important feature of the woodfuels consumption pattern in Ghana is the use of agricultural residues in the poorer regions of the country. As shown in Fig. 2.2 for the Upper East region, the population depending on agricultural residues for cooking is as high as 30% pointing to the scarcity of wood in many parts of the region and the endemic poverty levels that put even charcoal or other commercial fuels out of reach.

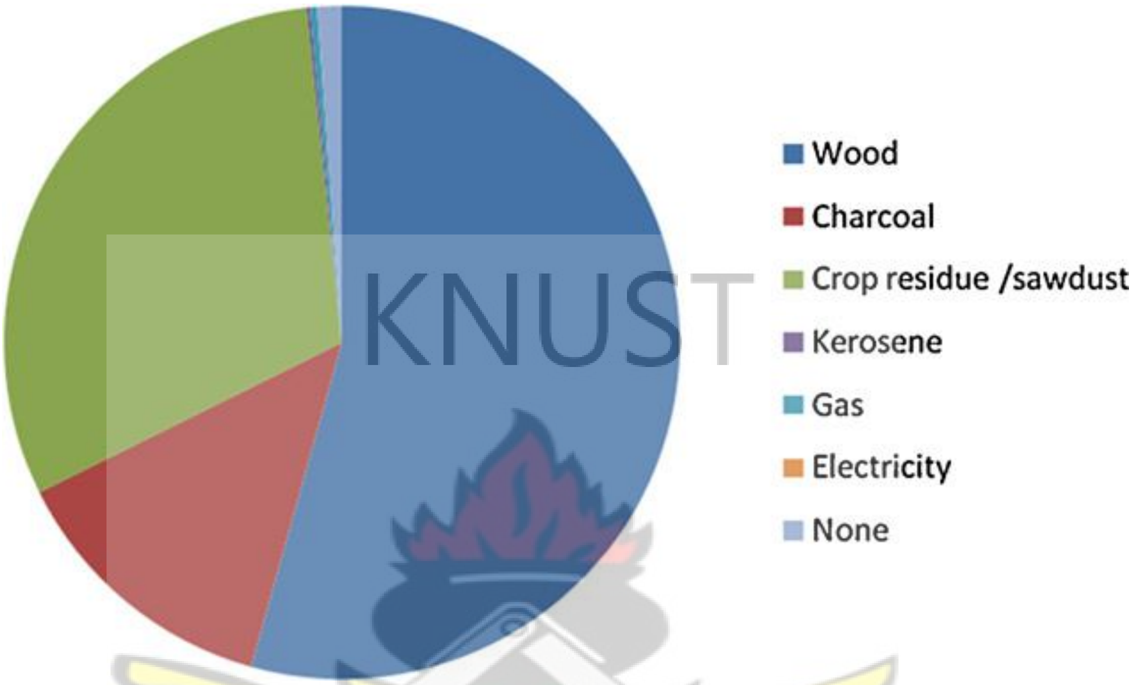

Figure 2.2: Types of cooking fuels used in the upper east region of Ghana.
Data source: [GSS, 2005]

2.5 Electrification Planning Decision Support tools

There are a number of GIS based electrification planning tools such as the HOMER, LEAP, Network Planner, etc. which can be used for energy access planning.

2.5.1 HOMER

HOMER is a computer model that simplifies the task of designing distributed generation (DG) systems - both on and off-grid. Its' optimization and sensitivity analysis algorithms allow you to evaluate the economic and technical feasibility of a large number of technology options and to account for variations in technology costs and energy resource availability. Originally designed at the National Renewable Energy Laboratory for the village power programme, it is now licensed to HOMER Energy [Homer, 2013].

It provides the detailed robustness of chronological simulation and optimization in a model that is relatively simple and easy to use. It is adaptable to a wide variety of projects. For a village or community-scale power system, it can model both the technical and economic factors involved in the project. For larger systems, it can provide an important overview that compares the cost and feasibility of different configurations; then designers can use more specialized software to model the technical performance.

It is accessible to a large set of users, including non-technical decision makers. Chronological simulation is essential for modeling variable resources, such as solar and wind power and for combined heat and power applications where the thermal load is variable. It's sensitivity analysis helps determine the potential impact of uncertain factors such as fuel prices or wind speed on a given system, over time.

It models both conventional and renewable energy technologies.

Power sources – Solar photovoltaic, wind turbine, run-of-the river hydro power, Biomass power, Generator - diesel, gasoline, biogas, alternative and custom fuels, co-fired, Electric utility grid, Micro turbine, Fuel cell. Storage – Flywheel, Battery bank, Flow batteries, and Hydrogen. Loads: Daily profiles with seasonal variation, Thermal (space heating, crop drying), and Efficiency measures.

2.5.2 Leap

LEAP, the Long range Energy Alternatives Planning System, is a widely-used software tool for energy policy analysis and climate change mitigation assessment developed at the Stockholm Environment Institute.

It has been adopted by thousands of organizations in more than 190 countries worldwide. Its users include government agencies, academics, non-governmental organizations, consulting companies, and energy utilities. It has been used at many different scales ranging from cities and states to national, regional and global applications.

It is fast becoming the de facto standard for countries undertaking integrated resource planning, greenhouse gas (GHG) mitigation assessments, and Low Emission Development Strategies (LEDS) especially in the developing world. Many countries have also chosen to use LEAP as part of their commitment to report to the U.N. Framework Convention on Climate Change (UNFCCC) [Heaps, 2012].

2.6 Network Planner

The NP was developed by the Earth Institute of Columbia University to model cost of electrification for communities not yet electrified in a country. The network planner can be used to quickly appraise connection costs and compare different regions and communities. The model defines the least-cost technology – either grid electrification, mini grid or an off-grid alternative – to connect an un-electrified community.

NP is a decision support tool for exploring electrification options in rural communities. It has been used to compare the long-term costs of installing solar, diesel or grid distribution networks and perform sensitivity analyses on variables such as demand growth for electrification plans in Kenya, Senegal and Ghana.

The NP projects electricity demand, compares costs for different electricity technology options and suggests where to extend the grid or other electrification technology alternatives. If the tool is provided with the location of existing grid lines, the system will optimize the grid extension to use the existing grid. If provided community-specific values for model variables, the system will use the community-specific values during computation.

The choice of the NP over other electrification planning tools, is its ability to compute detailed cost projections and operations research algorithms in a relatively short time with as little or as much data as is available.

2.6.1 The concepts of the model

Parameter Inputs

The input data used for modelling the un-electrified communities are clustered into five (5) categories: The default parameter used for the modelling can be found in appendix B. In Appendix B, it can be seen from the input parameters that some of the input data had changed slightly between 2010 and 2012 and this may affect the overall outputs from the results. Some of these parameters are: the Interest Rate per year, Elasticity of electricity Demand and Base Education Unit Demand.

1. Demographic Parameter - primary population, population growth rate, and mean household sizes which are needed to forecast population and household count to the base year, and to project electricity demand at the end of the time horizon;
2. Electricity demand – comprising four facility demand types: household, productive (such as water pumps, grinding mills, welding shops),

commercial (market places, shops, industries) and institutional (health, education, public lighting);

3. Geospatial data – these are the spatial location of the communities which are un-electrified and the existing grid network which are required by the model to compute distances, and therefore costs, to connect communities with MV line;
4. Socio-economic data – statistics on interest rate, economic growth rate and elasticity of electricity demand per year are all needed in appraising the discounted cost and projecting cost in a specified time horizon; and
5. Cost Parameter – both initial and recurring costs (such as fuel, operation and maintenance) of grid electrification and the two decentralised technologies (diesel generator as mini-grid and solar PV as off-grid). It is noteworthy that beside these above-mentioned options, any other decentralised technology options such as wind technology can be used. This research work uses the two solar PV and diesel generator as the decentralised electrification options because of the availability of cost and technical data, wide geographic applicability, and the suitability to communities.

2.6.2 Modelling projected population and its demand data

The growth of electricity demand of a location is reliant on its economic and population growth, as well as the settlement's total population. Higher economic and population growth rates have higher electricity demands, than settlements with larger total populations (towns and cities) which tends to have greater electricity demand per household than small villages. In the initial step, the user inputs the required parameters into the online tool, including the geospatial data (latitude and longitude coordinates) of the communities and the base year population of each. The model then applies different population growth rates to rural and urban areas based on the user-defined urban threshold (a value of population size below which a community is considered rural and above which is considered urban) in estimating the population to the last year of the planning time horizon. The model applied the population growth rate every subsequent year till the last planned year, including requirements allowing for a rural community to begin with rural growth rate level and end up with urban growth rate as its population passes the urban-rural threshold.

The combination of population growth rate (rural and urban), economic growth rate, mean household size, peak demand data and the base year electricity unit demands of the communities are used to determine the total electricity demands needed at the end of the specified time horizon.

The tool employs two kinds of user-defined curves to display the variation across settlements of different size in both the number of electricity demand points per settlement, and the magnitude of electricity demand at those points. The first is the "facility count curve," which plots the number of facilities of a given type (schools, clinics, commercial facilities) against the population of the settlement that contains those facilities at the initial time point. This creates a logistic curve, which quantitatively expresses the tendency for larger settlements to have more facilities of various types (i.e., cities have more schools and clinics than villages).

The second is the "logistic demand curve," which plots the variation in electricity demand for various points or structures (households, facilities) against changing settlement population. This creates another logistic curve, which expresses the tendency for homes and facilities in larger settlements to have higher electricity demand than homes or facilities in villages (i.e. hospitals demand more power than rural clinics; urban homes characteristically use more electricity on average than homes in the smallest villages). Both curves employ data from the model's starting year to create a logistic curve that can be used to predict a quantity – either number of facilities, or electricity demand for a given demand point – in the concluding year, based upon the expected population of a settlement. These curves are based on empirical data obtained from the relevant energy agencies and thus are an important aspect of localizing the model.

2.6.3 Modeling cost data for each technology

The tool requires detailed cost breakdown of the three electrification technologies such as the cost of medium voltage (MV) lines, low voltage (LV) lines, transformers, diesel generators, diesel fuel per litre, solar panels and solar batteries, as well as recurring costs, including operation and maintenance. Moreover, the model requires interest rate per year to be used to determine the discounted costs for each technology option which will be combined with other cost components in estimating the projected cost of electrification for each technology option based on the projected electricity demands at the end of the planning time horizon.

2.6.4 Selecting the least-cost technology option

In proposing the optimal-cost technology option for un-electrified communities, the tool first computes the total costs of electrification, including all initial and recurring costs, for the three different electrification technology options based on the projected electricity demands of the communities for a stated time horizon. These three potential electrification options include:

(i) Mini-Grid which is defined as diesel generator power with low voltage (LV) distribution for all demands type (domestic, productive, social infrastructure, etc.)

(ii) Off-Grid - which is defined as solar photovoltaic (PV) electricity for households augmented by a diesel generator for productive use and

(iii) Grid Electrification - This electrification technology comprises of two grid connections: "internal" and "external". The "internal" grid connection refers to cost for the secondary MV-lines, LV-lines, transformers and internal house wiring required to connect households, commercial structures and various institutions within a community. The "external" grid connection refers to extension of MV-lines from a transformer in the community to the nearest point of the MV grid network.

Subsequently, the model relates the discounted costs of the two decentralised, or "stand-alone" options (Off-Grid and Mini-Grid), and chooses the one with the least cost. The discounted cost of this least-cost standalone option is then compared with the discounted cost of only the internal component of grid connection costs for a community. If the least cost stand-alone option is lower in cost than the internal grid cost, this indicates that grid connection is not a viable option for that community, and the model designates the least-cost stand-alone technology as the final recommended electrification option.

However, if the internal grid component is less costly than the least-cost standalone option, then the difference in these two costs represents the budget available for the external component of the grid connection costs for such communities – viz., the MV line to connect to the nearest grid location. By dividing this value by the cost of MV-line per meter, the model obtains a key decision metric, ‘MVmax’ for each community. The MVmax, expressed in meters, represents the maximum length of MV-line which can be installed for each community before the cost of grid extension exceeds the cost of the least-cost stand-alone option. The metric is community specific and offers a simple assessment of how far the existing MV-line network can be economically extended to reach this community.

Lastly, the model applies a geospatial algorithm to compare these MVmax values with the actual distances between the location of unconnected communities (identified by latitude and longitude coordinates), and identifies those sites with MVmax values that justify grid connection. Those communities that are selected, indicating that grid extension is the most economical technology to electrify a community, are endorsed for grid connection by the tool; in other words, are said to be ‘grid-compatible’. Those communities beyond the MVmax values are in its place recommended for electrification using the least-cost stand-alone option.

2.7 Model Application – The case of Ghana in 2010

The Network Planner model was pragmatic to the situation of Ghana for the extension of electricity access to communities that are not electrified. The modeling was done on a regional basis to appreciate the total cost of electrification for the un-electrified communities in each region as each region has peculiar features in terms of the inputs model parameter that have to be considered. In this study, the year 2010 was chosen to be the base year coupled with a time horizon of ten (10) years due to the national energy target of universal electrification in 2020. All the input model data were acquired in 2010 except the population data of the un-electrified communities which were projected from the year 2000 to the year 2010 using a population growth rate recommended by the Ghana Statistical Services.

For the period of the modeling exercise, the following assumptions were considered as the base scenario: 100% penetration rate, current cost of diesel fuel per litre of \$1.02, 6 hours of operation of diesel mini-grid electrification, an average household demand of 150kWh per year for a population less than 500, and since all the un-electrified communities were rural (population < 5,000); a rural population growth rate was applied to estimate their population up to 2020.

During the sensitivity analysis the following listed assumptions were considered: penetration rates of 30% and 60%, cost of diesel fuel per litre of \$1.50 and \$0.75, a mean inter-household distance of 15 m, 25 m and 40 m, and lastly changes in household demands (down to 50 kWh/yr and 100 kWh/yr).

For the sensitivity examination, the Northern and Greater Accra regions were measured. What incited their selection was the variability in population densities of the regions, with Greater Accra having the most population density and Northern region having the least population density.

2.7.1 Community Analysis

In summary, outcomes obtained from the base scenario which denotes the best estimates of parameters and assumptions used in modeling the un-electrified communities in each region are shown in Table 2.2

Table 2.2 shows that by the end of the 10 year period, the most cost-optimized selection for majority of the yet to be electrified communities in each region will be grid compatible, accounting for over 70% of the total un-electrified communities in each region to be grid connected. This can be attributed to the widespread pre-existing grid network coverage over the country. However, it can be accepted that among the two decentralized options, the least average percentage number of un-electrified communities (6%) is designated to be the off-grid technology compatible (with two regions having no off-grid compatibility). It is worth stating that Northern region has the highest percentage of communities (19.5%) to be electrified by off-grid technology and this can be attributed to the low coverage of pre-existing grid network coupled with its remoteness (distance from the existing grid) of the communities in the region. Such percentages of communities that are located at a far distance from the existing grid network tend to be electrified by off-grid technology if that is the cost-optimized option among the two stand-alone options.

Table 2.2: Results obtained from the base scenario used for the modeling

Region	Percentage of Communities by region to be electrified by each technology			Cost Of Off-Grid (10yr, initial + recurring)		Cost Of Mini-Grid (10yr, initial + recurring)		Cost Of Grid (10yr, initial + recurring)	
	Off-Grid	Mini-Grid	Grid	Cost	Per HH	Cost	Per HH	Cost	Per HH
Ashanti	5%	15%	81%	$3,121,441	$3,563	$8,320,534	$3,224	$49,685,160	$2,213
Brong Ahafo	4%	21%	75%	$2,562,549	$3,564	$10,327,660	$3,255	$48,416,833	$2,152
Central	1%	3%	96%	$401,384	$3,431	$2,229,429	$3,101	$54,516,496	$1,886
Eastern	2%	6%	91%	$1,701,894	$3,598	$3,540,105	$3,192	$44,607,487	$2,120
Greater Accra		9%	91%			$438,546	$3,024	$2,420,494	$1,760
Northern	20%	10%	70%	$28,575,697	$3,491	$16,451,983	$3,302	$102,249,319	$2,397
Upper East	1%	1%	98%	$706,083	$3,395	$939,066	$3,109	$59,990,598	$1,882
Upper West	10%	9%	81%	$7,709,352	$3,378	$7,009,443	$3,229	$54,001,590	$2,252
Volta	2%	2%	96%	$1,839,250	$3,444	$2,374,145	$3,166	$80,057,241	$2,031
Western		6%	94%			$5,997,600	$3,334	$95,648,882	$2,126
High	**19.5%**	**21%**	**97.7%**	**$28,575,697**	**$3,598**	**$16,451,983**	**$3,334**	**$102,249,319**	**$2,397**
Avearge	**5.6%**	8%	**87.2%**	**$5,827,206**	**$3,483**	**$5,762,851**	**$3,194**	**$59,159,410**	**$2,082**
Low	**0.5%**	1%	**70.2%**	**$401,384**	**$3,378**	**$438,546**	**$3,024**	**$2,420,494**	**$1,760**

At the national level, average connection cost per household for grid electrification is $2,082 and the total cost (capital cost including costs of electricity generation which is integrated in terms of the per kWh tariff paid to meet the electricity demands plus recurring costs of the various technologies components) totaled $59,159,410 for 10 year planning period. It can be noticed from Table 2.2 that the total cost of off-grid electrification for the period amounted to $5,827,206. Conversely, the average connection cost per household of off-grid electrification is higher ($3,483) as compared to the other two technology options and this is so because the total cost of off-grid electrification is shared among a fewer number of households electrified with off-grid technology in each region. This infers that the number of households in a community to be electrified by a certain electrification technology have direct bearing on the average connection cost per household as the higher the number of households in a community to be electrified, the lower the connection cost and vice versa. **[Kemausuor et al, 2010].**

CHAPTER THREE

METHODOLOGY

Literature was sought in order to get acquainted with the relevant works that have been carried out on the network planner so far by relevant bodies and partner institutions.

Analysis was carried out by using results from 2010 and updated database results from 2012, with particular emphasis on the Northern and Greater Accra regions.

Based on the result from the updated electricity access data for the ECG and NED operational areas, the total cost of electrification access was examined using Network Planner with special emphasis on the inter-household distances. The inter-household distances were measured with the aid of GIS software and some assumptions as well.

In this study, the results in the year 2012 will be used to compare with the base year (2010). The current population data of 2010 from the Ghana Statistical Service also served as the input into the model.

For the sensitivity analysis the following listed assumptions was made:

- penetration rates of 30%, 60% and 100%,
- cost of diesel fuel per litre at current prices, and
- Mean inter-households distance at the base scenario of 25m and at 40m for both regions in the year 2012.

3.1 Data Acquisition Model Chart

The flow chart below shows in a simple step by step the process from data acquisition to the output map for the network planner.

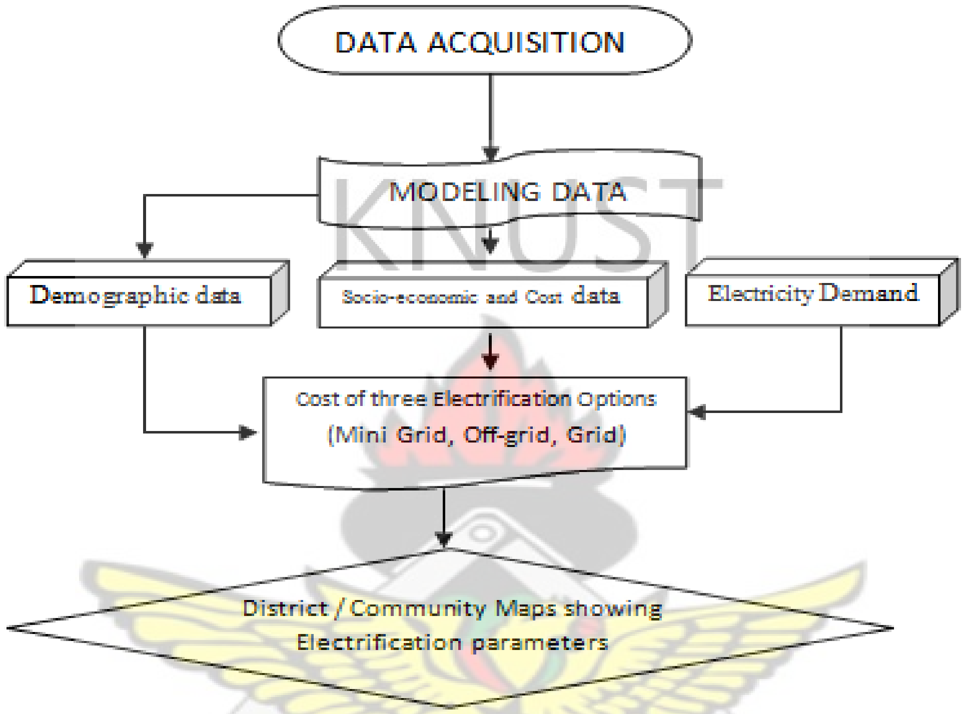

Fig 3.1 Model Chart for the Network Planner

3.2 Improvement in the model

The model input parameters had been altered to improve on the output from the model making analysis easier from the results. The metric model was run in default as 'mvMax3' but now has a default value of 'mvMax4'. The output file from the analysis was the metric-local.csv but now two output files are required from the model output files which are the metrics-local.csv from which we obtain the growth and demand projections, cost (recurring and initial) and recommended system type, and the metrics-global.csv which has the network output – total MV line length, discounted cost, existing and proposed network length.

Secondly, in processing the results, the figures to be created is a table with number and percentage of households recommended for each technology, with initial and yearly recurring costs, Household system numbers by settlement size plotted as a graph after household bins classes have been pre-defined.

Thirdly, the output files are in .csv format which have to be converted to .xlsx formats for processing.

3.3 Limitations of the model

Although, the model has been recognized to provide a timely and effective tool for national electrification planning, the following listed limitations should be noted:

- The network planner connects communities to the grid in straight lines disregarding most geographical and technical constraints. The capital cost may be increased if these limitations – and particularly the need for the grid to follow major roads – are considered.
- Assumptions and estimations on cost used in the models reflect the best available data. However, costs are constantly changing due to technological and economic reasons and the model assumes that the conditions will remain the same for the time horizon specified which in actuality would not be the case.
- The model needs to be upgraded to be able to consider more mini-grid and decentralized options aside diesel generators and SHS.

3.4 Interphase of the Network Planner Model

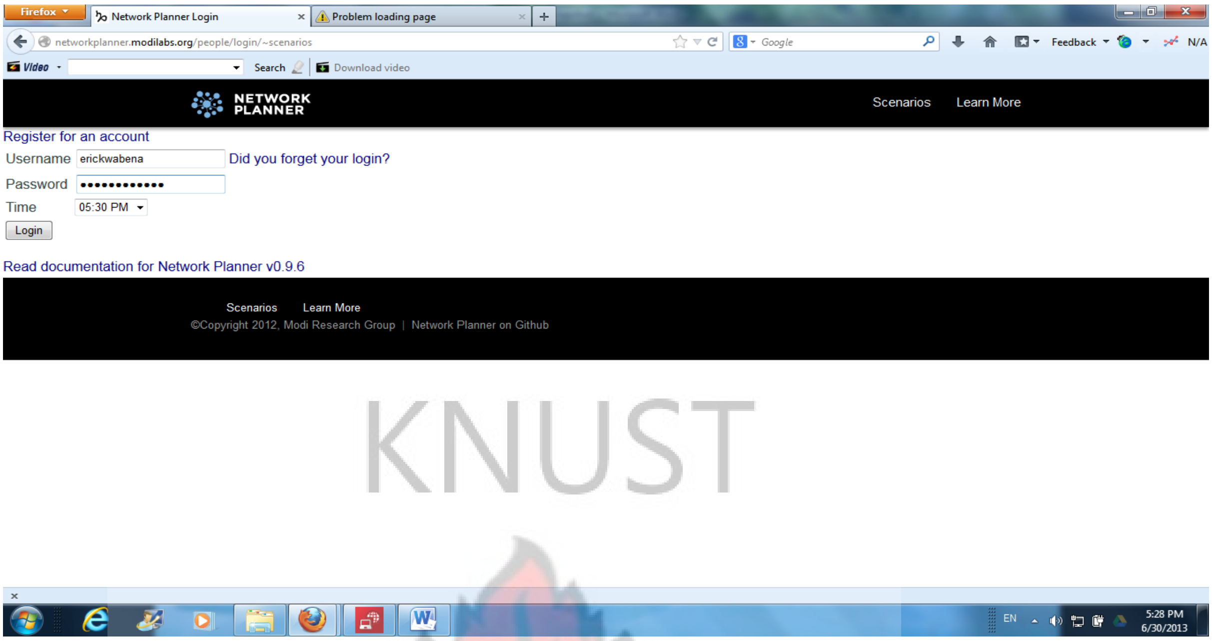

Fig 3.2: snapshot showing the sign-in page of the Network Planner

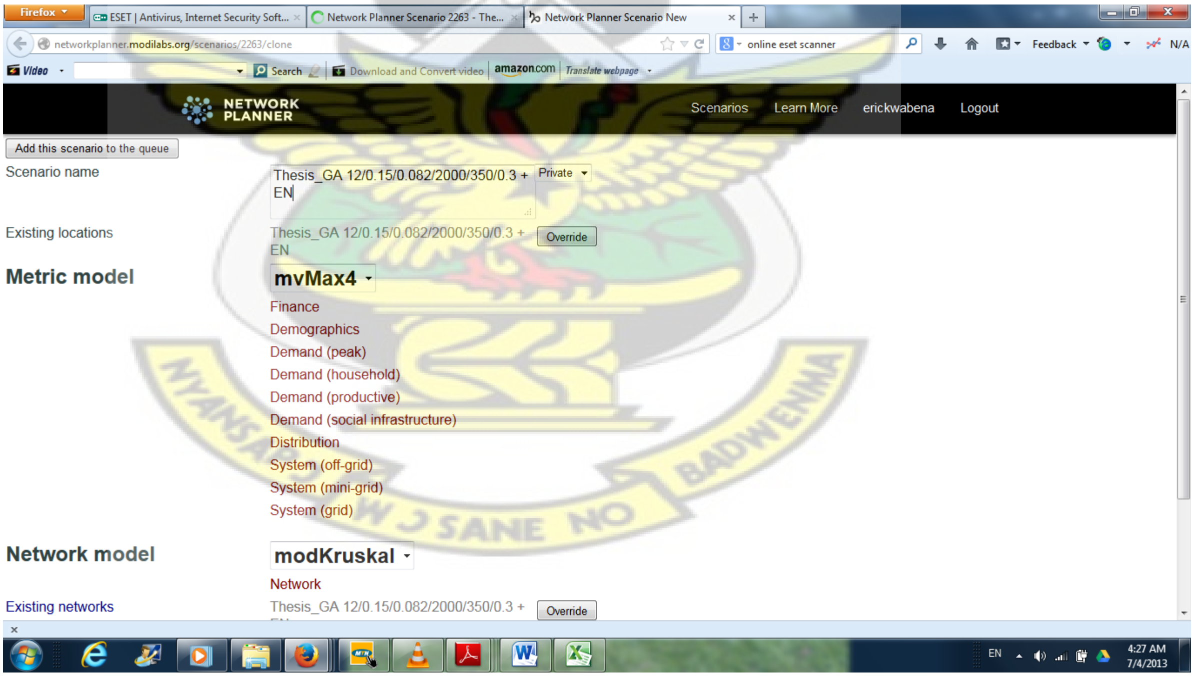

Fig 3.3: Snapshot showing the input parameter page of the network Planner

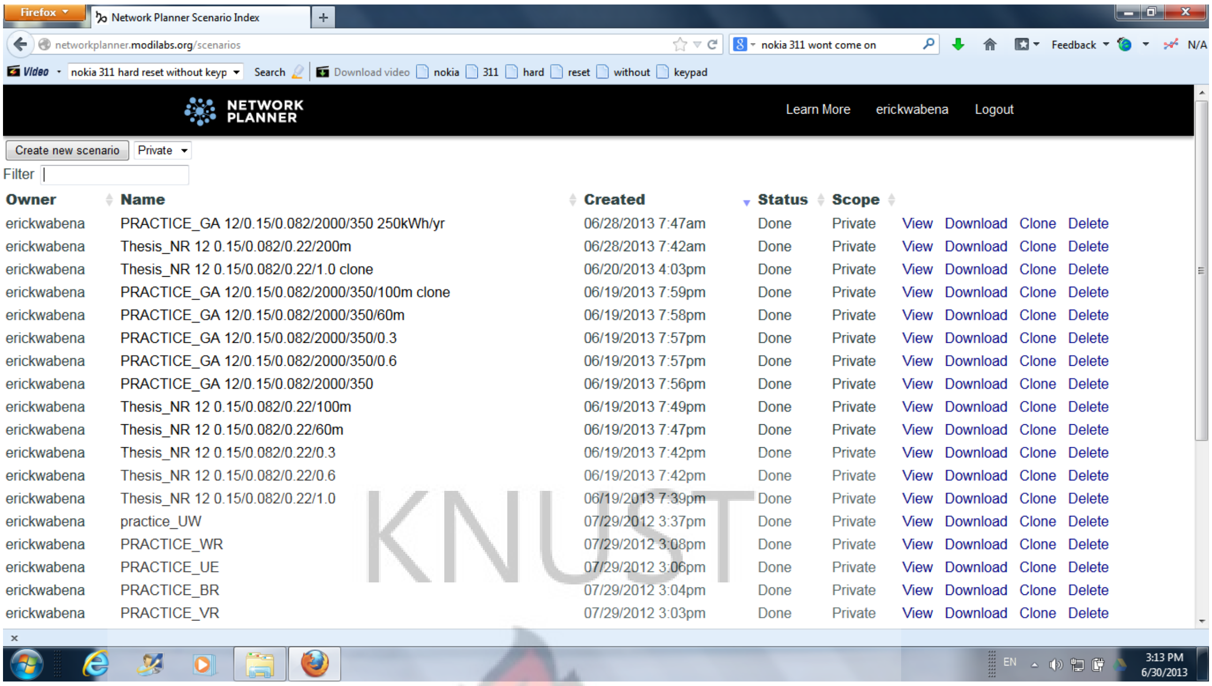

Fig 3.4: Snapshot showing the scenario page after signing into the network planner.

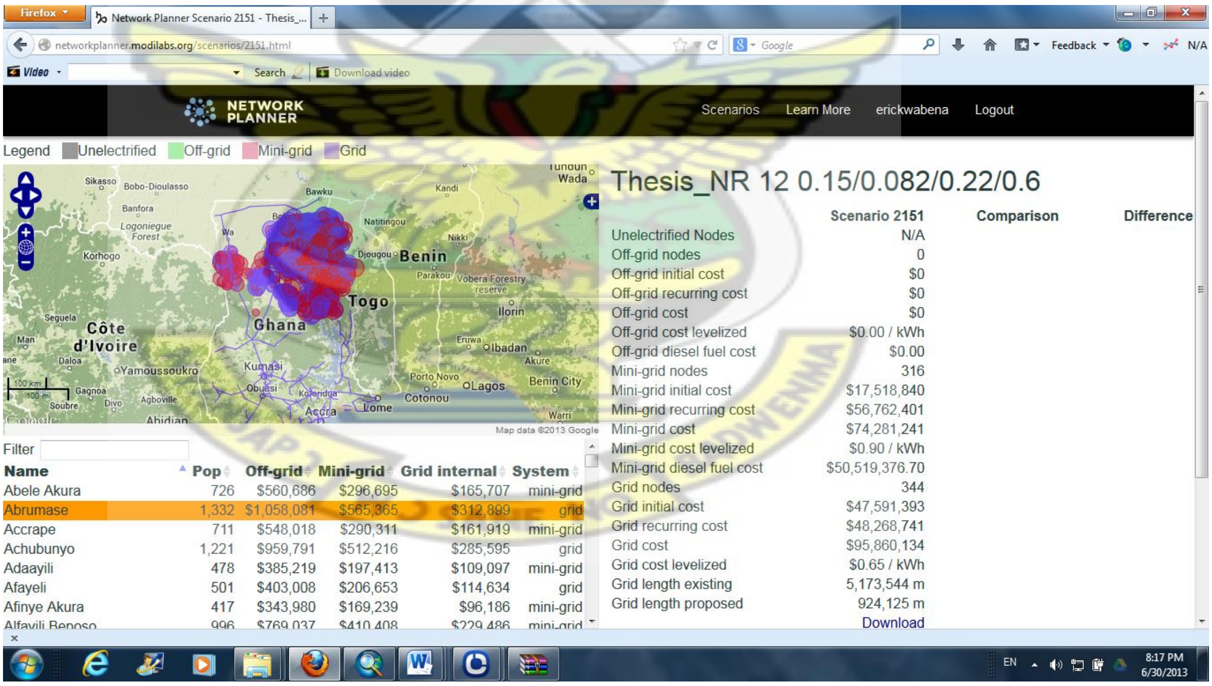

Fig 3.5: Snapshot showing the output page of the network planner

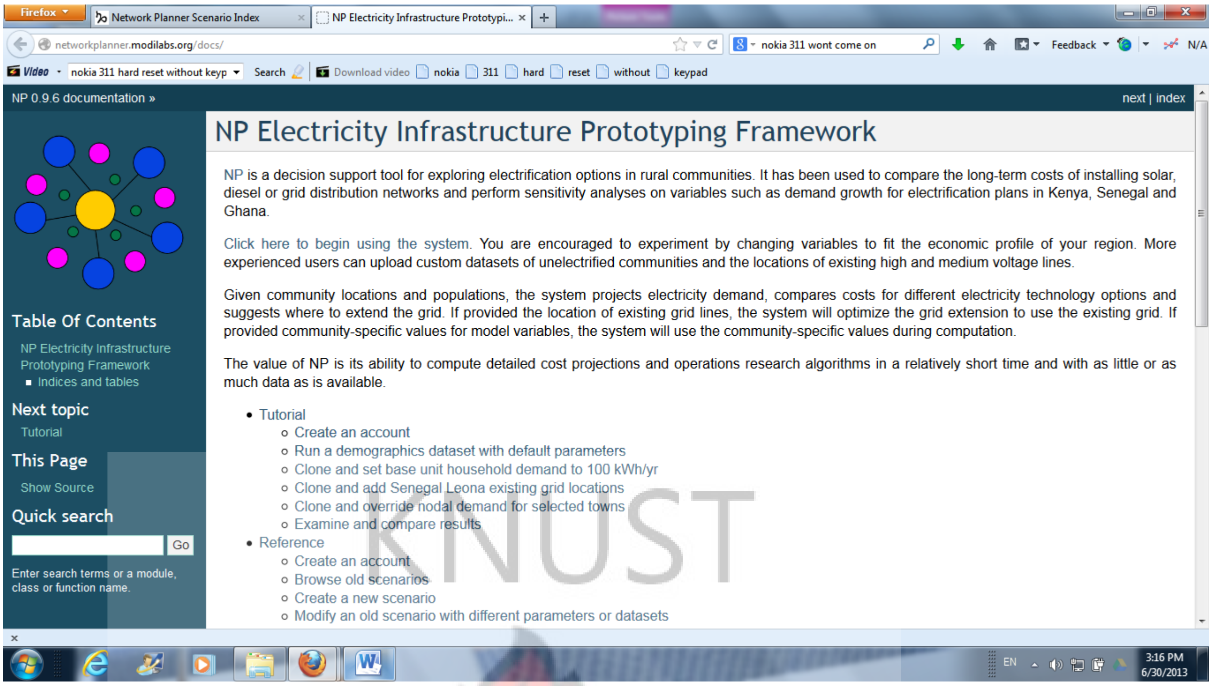

Fig 3.6: Snapshot showing the information page of the network planner

CHAPTER FOUR

RESULTS AND ANALYSIS

4.1 Community Analysis

The results obtained from the base result in 2010 and compared with 2012 which represents the estimates of parameters and assumptions used in modeling the un-electrified communities in both regions are summarized in Table 4.1.

Table 4.1 shows that by the end of the 10 year period, the most cost-optimized option of the un-electrified communities is the grid connection. This is more evident when comparing the cost per household in both regions. This is in agreement with the results obtained in 2010 for all communities which were modeled. Another factor leading to this is the already existing extensive pre-existing grid network coverage over the country, which reduces the distances and hence, the cost to connect remaining communities to be electrified.

Between the two decentralized options, no community is designated for off-grid technology in 2012 as compared to the base scenario results obtained in 2010. It is also clearly shown that there is a significant decrease in the total cost of electrification for grid technology in the Greater Accra region while it increases in the northern region. This is as a result of more communities being electrified as well as having a more dense population in Greater Accra as compared to the Northern region.

Table 4.1: Results obtained from modeling the base scenario on cost of electrification for the various technology options comparing with the year 2012.

Region	Number of Un-electrified Communities	Percentage of each electricity technology recommended by the model to serve un-electrified communities						Cost of Off-Grid (US$) (10yrs, initial + recurring)				Cost of Mini-Grid (US$) (10yrs, initial + recurring)				Cost of Grid (US$) (10yrs, initial + recurring)			
		Off-Grid		Mini-grid		Grid		2010		2012		2010		2012		2010		2012	
		2010	2012	2010	2012	2010	2012	Total	Per HH	Total	Per HH	Total	Per HH	Total	Per HH	Total	Per HH	Total	Per HH
Greater Accra	11			9%	16%	91%	84%	-	-	-	-	438,546	3024	307,291	1,330	2,420,494	1760	1,423,158	1,208
Northern	660	20%		10%	20%	70%	80%	28575697	3491	-	-	16,451,983	3302	23,241,332	1,320	102,249,319	2397	120,610,855	1,671

At the national level, the average connection cost per household for the grid electrification and the total cost (capital cost plus recurring costs, including cost of electricity generation which is incorporated in terms of the per kWh tariff paid to meet the electricity demand) will be adjusted accordingly for the ten year planning period. The average connection cost per household for grid electrification is usually lower than the other two stand-alone options per region. The reason is that off-grid and mini grid electrification is generally more costly due to high recurring costs, particularly for diesel fuel and replacement of batteries for the solar PV system.

Cost of grid connection can take advantage of economies of scale: households in a grid compatible community would share the total infrastructure cost of the initial extension of the medium voltage grid line and transformer to supply the community. The result is lower cost per connection for larger communities but in contrast, the connection cost of off-grid does not usually scale in the same manner except for the lowering cost of some cheap imported generators and parts or some tax waivers from the government or support from other bodies.

4.2 Inter-Household Distances, proposed Grid Length and Levelised Cost of Electrification (LCOE) Analysis

Table 4.2 shows the required grid extension lengths for the proposed MV and LV lines at the base scenarios which is at 25 m and also at 40m for the communities and the levelised cost per each electrification option in both regions.

It can be observed from table 4.2, that the total lengths of MV line length for the regions remained the same at the base scenarios while the LV-lines needed to connect communities in the two regions vary extensively at either 25 m and at 40 m.

It can also be seen that for the LV-lines, there is a slight increase in the length in 2012. This is because Greater Accra is densely populated and so the un-electrified households are within radius while for the Northern region it is observed that a greater increase in the LV- line length also is stemming from the fact that the Northern region is sparsely populated which accounts for the increase in line length.

Table 4.2 also shows the levelised cost of grid technology for both regions are lower as compared to the levelised cost for the two other decentralized technology options. Here the levelised cost of each technology in each region represents the total cost of electrification for each technology including all recurring costs for the ten year planning period duration, divided by the sum of all the electricity supplied in kWh of only those communities designated by each technology in the two communities in the base year and in 2012.

To a certain degree, LCOE is inversely proportional to the total electricity demand. Higher demand normally justifies investment in technologies that have a higher initial cost, but lower long-run cost, at higher density, which inclines to lower per unit cost of electricity delivery. It is usually inexpensive to provide power to an already existing grid line to communities as compared to solar and mini-grid, due to high recurring cost of the stand-alone options (batteries for solar and diesel for generators). We can however have a lower LCOE for stand-alone options for communities' particularly smaller ones distant from the grid – where the high initial cost of grid extension will not prove cost effective, even when averaged for years. For these communities, the least cost option will remain the off-grid technology at least for the limited time horizon (10 years) of this planning exercise.

Table 4.2: Inter Household Distances and effect on proposed line lengths and levelised Cost of Electrification obtained at base scenario for the year 2010 and 2012 for both regions.

Region		Length of proposed MV Lines (meters)		Length of Proposed LV Lines (meter)				Levelised Cost (US$ per kWh)					
		Total		Total		Per HH		Off-Grid		Mini-Grid		Grid	
	Inter HH Distance	2010	2012	2010	2012	2010	2012	2010	2012	2010	2012	2010	2012
Greater Accra	25m	41,368	26,488	34,125	34,950	24.8	24.8	-		0.97	0.9	0.56	0.61
	40m	41,368	26,488	54,628	55,920	39.7	39.69	1.11		1.05	1.11	0.62	0.82
Northern	25m	1,585,047	1,861,745	1,054,900	2,226,825	24.7	24.8	1.1		1.02	0.91	0.66	0.65
	40m	1,585,047	1,861,745	1,691,257	3,562,920	39.6	39.71	1.1		1.04	0.99	0.7	0.73

4.3 Cost Analysis with emphasis on penetration rate

Initial cost and total cost (including initial and discounted costs for the ten year period) of electrification in the two communities are summarized in table 4.3. The table compares the combined cost of electrification for all three electrification technologies under three penetration rates (PR) scenarios: the full penetration rate at 100% - defined as electrification of all household in each un-electrified community in the regions – while the other rates at 60% and 30%, defined as electrification of all communities in both regions, but including only 60% or 30% of households within each community. To obtain the full penetration rate employing all the three electrification options, the total initial cost is estimated to be US$116,227,158 in 2012 as against US$87,589,547 in 2010. In comparison to the other two penetration rates reveal total initial cost of US$66,057,479 and US$30,748,678 for penetrations rates of 60% and 30% respectively in 2012 and US$55,093,691 and US$27,363,753 as penetration rates at 60% and 30% respectively for 2010. The total cost of electrification (including initial and recurring) at 100% penetration rate totaled to US$159,136,039 by the end of the time horizon.

Table 4.3: Total and initial cost of all combined electrification technologies at each penetration rate

Region	Cost of ALL ELECTRIFICATION, US$ (Grid, Solar off-Grid and Diesel mini-grid)											
	PR = 100%				PR = 60%				PR = 30%			
	Total		Initial		Total		Initial		Total		Initial	
	2010	2012	2010	2012	2010	2012	2010	2012	2010	2012	2010	2012
Greater Accra	2,859,040	1,730,449	2,021,299	1,487,725	2,124,197	1,195,493	1,239,306	904,877	1,346,978	603,427	718,903	420,825
Northern	147,276,999	143,842,187	85,568,248	114,739,433	103,512,748	86,102,422	53,854,385	65,152,602	67,212,069	43,955,577	26,644,850	30,327,850
Total	150,136,039	145,572,636	87,589,547	116,227,158	105,636,945	87,297,915	55,093,691	66,057,479	68,559,047	44,559,004	27,363,753	30,748,675

It can be deduced from table 4.3 that the cost of electrification is higher at 100% penetration rate and drops down as the rate of penetration decreases.

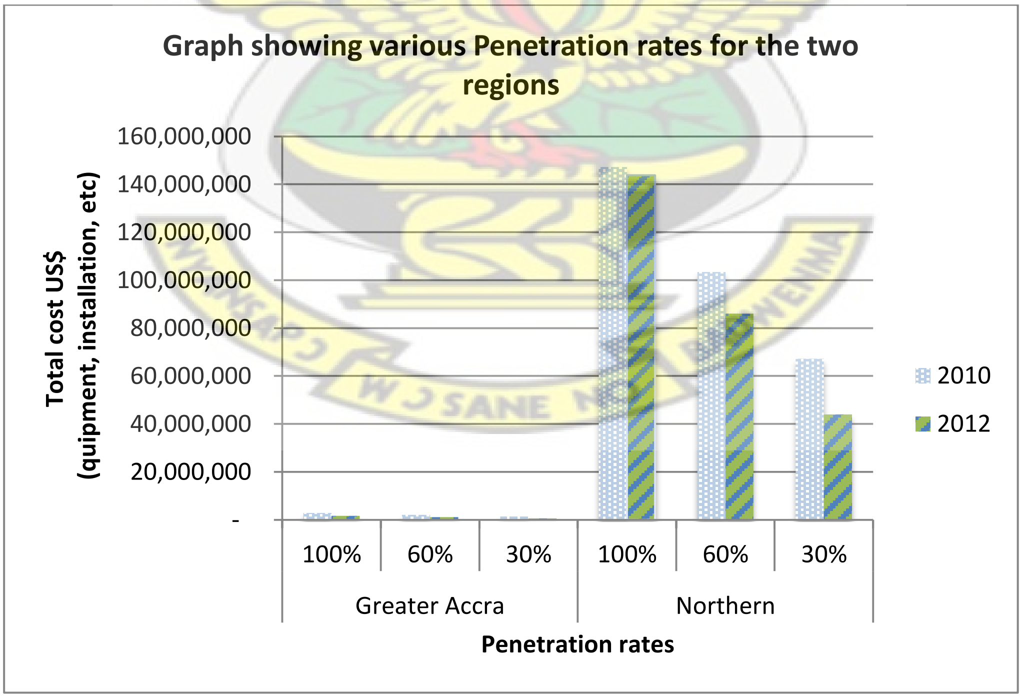

Fig 4.1: Graph showing comparison of the total cost of electrification of all the technology option under the penetration rate scenarios for the two regions.

Fig 4.1 shows the results of the factors that contribute to the very high cost of electrification in the northern region include: (i) low existing grid network coverage coupled with a large number of relatively remote un-electrified communities. These are reversed for Greater Accra, which has the least total cost of electrification. These electrification costs variance provide a useful guide in planning and financing needed either from government or private sectors to achieve Ghana's objective of universal access by 2020.

4.4 Sensitivity Analysis

Sensitivity analysis was performed to understand the consequence of changes in parameters such as inter-house distances on the model results. Greater Accra and Northern regions were chosen for this thesis work because they represent two extremes of population. Greater Accra has the highest population density and Northern region the least. In carrying out the analysis, the base scenario was maintained (best estimates of parameters and assumptions, explored in details in previous sections), while the other scenarios were run with variations in the following key parameters: Diesel fuel cost, Household (HH) demand, Mean inter-household (inter-HH) distance and penetration rate. It should be highlighted here that, in the running of the scenarios all other input parameters and assumptions, aside from the afore-mentioned parameters are the same as the base scenario.

4.4.1 Effect of diesel fuel cost changes

When the analysis was carried out in 2010, it was observed that lowering the cost of diesel resulted in a shift in the percentage of the un-electrified communities designated for off-grid or grid technology in the base scenario to the mini-grid technology. However, increasing diesel fuel cost impacts the cost of other electrification technologies – grid and off-grid. [Kemausuor et al, 2010]. This trend was also observed in the current analysis.

4.4.2 Effects of household demand change

It was observed that lowering the household demand to 100kWh/yr from the base scenario of 150kWh/yr resulted in a substantial shift in the number of un-electrified communities that were grid-compatible in the base case toward off-grid compatibility in the 2010 analysis. It was observed that the percentage of un-electrified communities that were mini-grid compatible remained the same. It was also gathered that household demand and required proposed length of MV grid lines needed to connect households in the communities to the existing grid network lean towards rising together. In conclusion, the lower the household demand, the lower the required MV grid length needed to connect communities and vice versa.

4.4.3 Effects of mean inter-household distance (MID) changes (base scenario vs. current year)

For Greater Accra, analysis carried out in 2010 (base scenario) revealed that an increase in mean inter-household distance (MID) tends to favour off-grid electrification while a lower MID favoured un-electrified communities to the mini-grid and grid – technology. This can also be noticed in the LCOE. Furthermore, an increase in MID from 25m (base scenario) to 40m results in an increase in the proposed LV-line length but the proposed MV-line length remained the same.

In the case of Northern region, however, there is a gradual decrease in the percentage of communities that are mini-grid compatible as MID increases. This is because the Northern region is the largest region in Ghana with low population density and less existing grid network coverage. Generally we can also see that the grid technology is still the most compatible with respect to all the available technologies.

For the current year as explained in detail in section 4.2, the total length of MV and LV-lines needed to connect households in the two regions vary extensively. It can also be seen that the total length of LV-lines increases slightly for Greater Accra partly due to a more densely populated area as compared to the increase for that of the Northern region and also largely due to the fact that it is characterized by high existing grid network penetration for both 25 m and 40 m inter-HH distances. The MV lines remain the same for both regions even with increases in inter-household since the LV lines are what is used to connect the various households.

4.4.4 Effects of a change in penetration rate

For this assignment, scenarios with multiple penetration rates were run in the year 2010 to address the government policy targeting connection of at least 30% of households in every community in Ghana. It can be deduced that a penetration rate of 100% (base scenario) results in a high percentage of un-electrified communities to be grid compatible and at a low average connection cost per household. Extra reduction of penetration rate to 60% and 30% also shift a significant percentage of communities that were grid compatible to be compatible with either of the two stand-alone technologies. It has been shown that lowering penetration rate tends to lower the total cost of electrification per each technology option for an entire region, however it increases the connection cost per household. The reason for higher connection cost per household with lower penetration rate is the spread of the same infrastructure costs (such as MV line and transformers required to connect the community) over fewer households. In 2012 as discussed into detail in the earlier section, we observe a corresponding decrease in the cost of the various technologies as the penetration rates reduces.

4.5 Summary of modeling results

The network planner model results can be used by decision makers and electricity planners to make investment estimates and meet requirements for a range of electrification programs given various technology options, governmental policies, fuel cost and so on. In addition, planners can use this tool to identify those un-electrified communities that may tend to be grid compatible and those communities that will incline to be off-grid or mini-grid compatible within the specified time horizon either at national or local levels.

It has been shown that, by the end of the ten year planning period, majority of un-electrified communities will be viable for grid expansion with some fewer number of communities being mini-grid compatible and not for off grid electrification as recommended in the base year 2010.

It has also been shown that the penetration rate has a major influence on the total cost of all electrification options as well as the connection cost per household. Lowering the penetration rate tends to lower the total cost of all the electrification whereas the connection cost per households increases since the same general infrastructural cost is pooled among fewer number of households.

Lowering the mean inter-household distance (MID) tends to shift more communities to be grid compatible since the households are now closer to each other.

From the initial analysis it was revealed that the MID determines the required length of LV-grid lines for connecting the households.

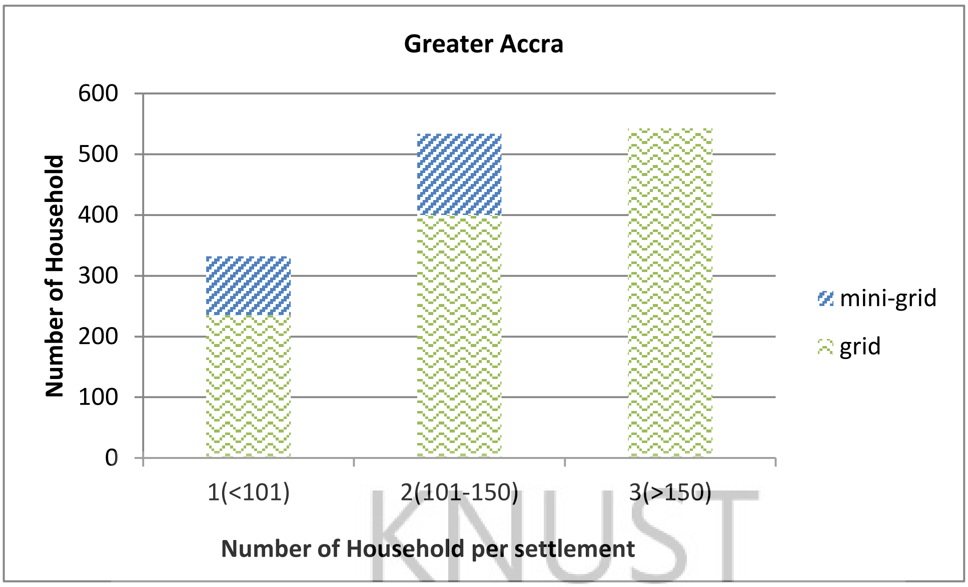

Figure 4.2 Classification into Number of Households per settlement per technology for the base scenario in the year 2012 for Greater Accra.

Figure 4.2 shows the base scenario for Greater Accra with communities with a household per settlement of 100 and below and between 101 – 150. The model proposes both grid and mini-grid while in the case of households per settlement greater than 150 the system proposes the grid technology for those communities.

From Appendix A fig (a), in terms of the base scenario with a penetration rate of 30%, the model proposes at HH per settlement less than 101 for mini-grid while for HH per settlement greater than 100 they share between the grid and mini-grid technology.

However, from Appendix A fig (b), with a penetration rate of 60%, the model proposes both grid and min-grid for HH settlement sizes of below 150, while it proposes grid technology for HH settlement sizes of above 150.

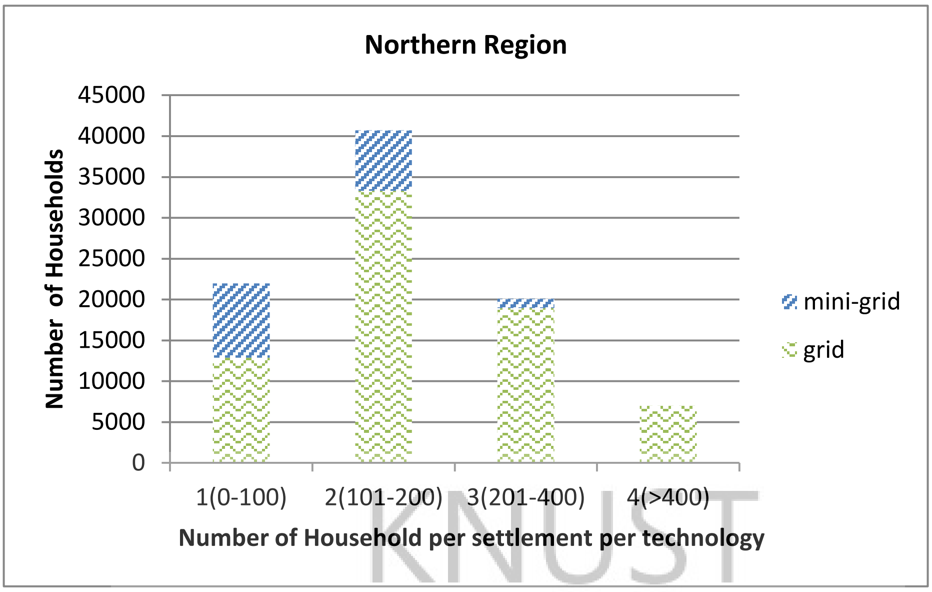

Figure 4.3 Classification into Number of Households per settlement per technology for the base scenario in 2012 for Northern Region

Figure 4.3, base scenario for the Northern region at 100% penetration rate and inter-HH settlement size, the model proposes a mix of grid and mini-grid with grid having a greater share with population size below 400. The model proposes grid technology for population size greater than 400.

From Appendix A fig (c), the base scenario for Northern region with a penetration rate of 30%, the model proposes both grid and mini-grid for all the HH settlement sizes.

In Appendix A fig (d), with a penetration rate of 60%, the system also proposes the grid and mini-grid but at different ratios as shown clearly.

4.6 Output Maps from the Network Planner using ArcMap Software

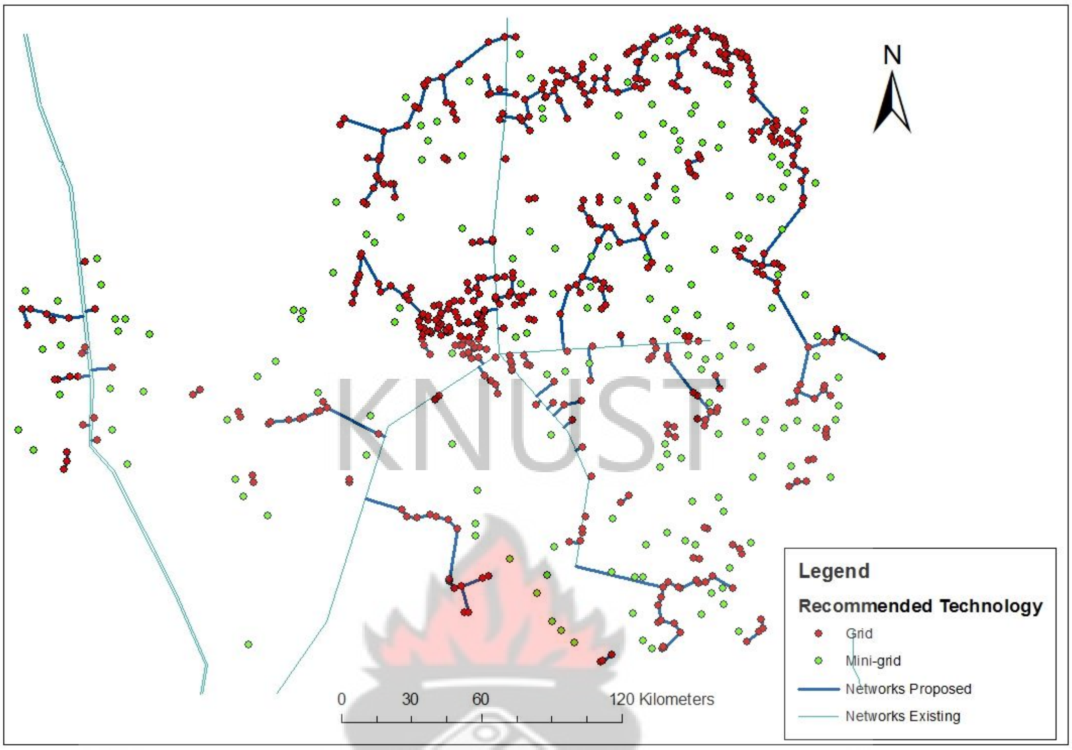

Fig 4.4: Map showing the recommended electrification technology for both proposed and existing network for the Northern Region of Ghana

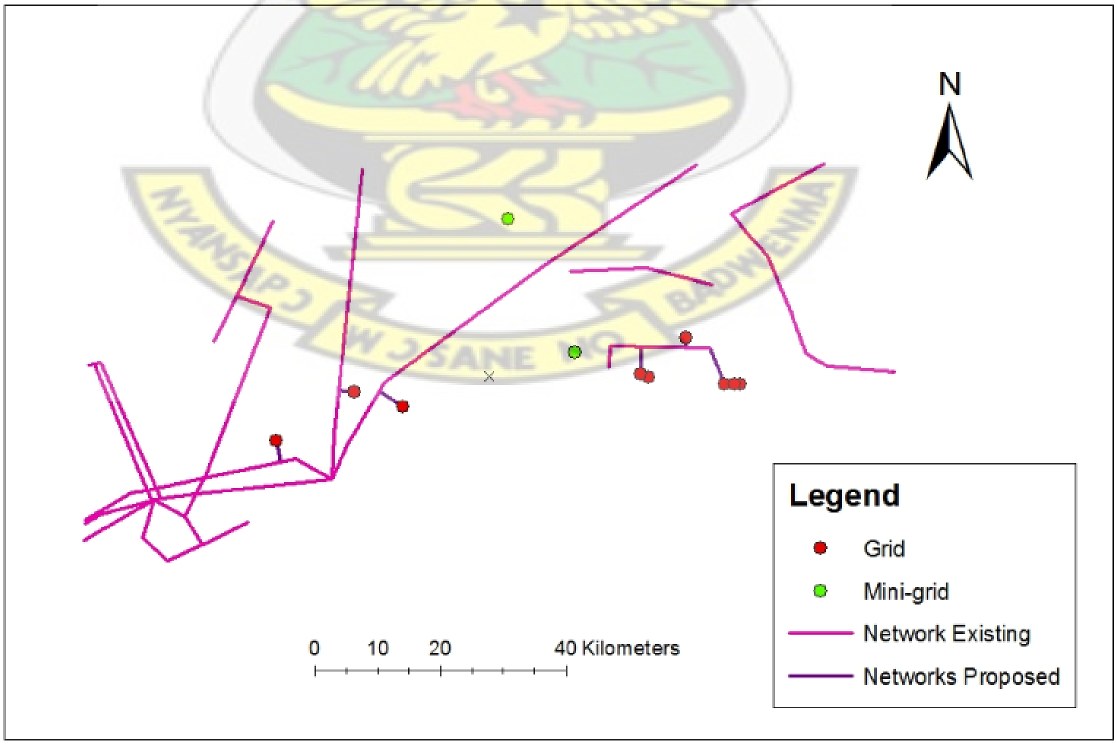

Fig 4.5: Map showing the recommended electrification technology both proposed and existing network for the Greater Accra Region of Ghana

Figure 4.4 is a map showing the recommended technologies for the Northern region using ArcMap software. The red dotted markings show the communities which should be grid connected while the green dotted markings show the communities which the model proposes to be mini-grid. From the map, no community is recommended for off-grid technology.

One of the considerations for the system deciding for the grid technology for a community could be proximity to the grid but again it could still be dependent on the settlement sizes to determine if it is cost-effective as compared to the other technologies.

Figure 4.5 is a map showing the recommended technologies for the un-electrified communities in the Greater Accra region, the red markings show that there are just eight communities that are recommended for grid and two communities that the system proposes for mini-grid. Again there are no recommendations for off-grid. Greater Accra has very few un-electrified communities with an already existing widespread grid network.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The review and assessment carried out has shown that Ghana has made momentous strides in electricity access due to long-range energy planning with clear targets, political/popular demand and proactive role of central government in the implementation of energy access plans in just few years.

The network planner can help planners and investors make informed decisions because it clearly shows the cost of achieving electrification targets with the various technology options and also at the various rate of penetration over the planning time horizon.

The major conclusion can be summarized as follows:

- It has been shown that the penetration rate has a major influence on the total cost of all the electrification options as well as the connection cost per household. Lowering the penetration rate tends to lower the total cost for grid electrification option whereas the connection cost per household increases since the same general infrastructural cost is pooled among fewer number of households.
- Reducing the mean inter-household distance (MID) tends to shift more communities to be grid compatible since the total cost per household will be lower and hence lower cost for grid technology. It revealed that the MID is the deterministic factor of the required length of LV grid lines for the connecting households.
- It can also be pointed out that lowering the diesel fuel cost per litre results in a higher percentage of diesel mini-grid compatible communities. It should also

be noted that diesel cost also affects the other electrification technologies.

5.2 Recommendations

A number of recommendations coming out of the results of this thesis include;

- ✓ The combination of Solar PV and other electrification technology option in national electrification programmes,
- ✓ Proper coordination of energy access data (EAD), and
- ✓ The need for efforts to address collection of correct and up-to-date data from the communities.

5.2.1 Renewable energy system integration in electrification programs

Planners should ensure the integration of Solar PV and other renewable energy systems into the electrification plans at both the national, regional and community levels.

The use of Network Planner should also be encouraged to determine what technology such as grid electrification, mini-grid and decentralized options like Solar Home System (SHS) would be suited for the various yet-to-be electrified communities. The network Planner software also needs to be upgraded to be able to consider more mini-grid and decentralized options aside diesel generators and SHS.

5.2.2 Dynamic and shared energy Access database

The need for more work to generate a database for determining the energy access improvement pattern over the years as this would help provide more accurate inputs and as well projections towards energy access planning.

Data should be harmonized from different institutions or sources. Data sources should be given proper time stamps and a methodology for computation should be agreed to allow for a good historical analysis to provide a more robust report on the trend of energy access rates at whatever levels.

REFERENCES

Abakah E. A review of economic growth and energy consumption in a developing country: Ghana. OPEC Review, Oxford 1993; 17(1):47–61.

ADBG; http://www.infrastructureafrica.org/documents/search?Sector=244&Theme=All& Country=43&REC=All. Accessed 2013.

Akuffo FO. Electricity for all in Ghana: (2009) when and how? Paper Presented at the John Turkson Memorial Lectures on Energy.

Alternative Energy Africa. Ghana gets a taste of India; 2009. http://aefrica.com/read article.php?NID=792, accessed 2009.

Botchway FN. The state, government and the energy industry in Ghana. Verfassung und Recht in Ubersee, Baden-Baden 2000; 33:135–211.

Brew-Hammond A, Kemausuor F. Energy for all in Africa—to be or not to be? Current Opinion in Environmental Sustainability 2009; 1:83–8.

Bugaje IM. Renewable energy for sustainable development in Africa: a review. Renewable and Sustainable Energy Reviews 2006; 10:603–12.

Deichmann U, Meisner C, Murray S, Wheeler D. The economics of renewable energy expansion in rural Sub-Saharan Africa. Energy Policy 2011; 39: 215–27.

Denton F. Analysis of policies and institutions and linkages with energy SME development: Ghana, Mali, Senegal, Tanzania and Zambia. Denmark: AREED Policy Review: (2006) UNEP Risoe Centre.

ECOWAS (2005). White paper for a regional policy geared towards increasing access to energy services for rural and peri-urban populations in order to achieve the Millennium Development Goals, Supported by UNDP and French Ministry of Foreign Affairs.

Energy Commission. 2004; Energy review. Official Journal of the Energy Commission of Ghana.

Energy Commission. Energy statistics 2005. Accra, Ghana: (2005) Energy Commission.

Energy Commission. Energy statistics 2007. Accra, Ghana: (2007) Energy Commission.

Energy Commission. Strategic national energy plan 2006–2010. Accra, Ghana: (2006) Energy Commission.

F; Adu-Poku I; Ladzagla D. (2010). GIS-Based Support For Implementing Policies And Plans To Increase Access To Energy Services In Ghana.

Ghana Statistical Service. Ghana 2003 core welfare indicators questionnaire (CWIQ II) survey report. Accra, Ghana: (2005) Ghana Statistical Service.

Ghana Statistical Service. Pattern and trends of poverty in Ghana (1991 – 2006). Accra, Ghana: (2007) Ghana Statistical Service.

Haanyika CM. Rural electrification policy and institutional linkages. Energy Policy 2006; 34:2977–93.

Heaps, C.G. (2012). Long-range Energy Alternatives Planning (LEAP) system. [Software version 2012.0049] Stockholm Environment Institute. Somerville, MA, USA. www.energycommunity.org

HOMER. 2013. http://homerenergy.com/software.html accessed 2013.

IEA. World energy outlook. Paris. (2012). International Energy Agency.

Kankam S, Book EK. Energy delivery and utilization for rural development: lessons from Northern Ghana. Energy for Sustainable Development 2009; 13:212–8.

Kemausuor F; Brew-Hammond A; Obeng G.Y; Alfred Duker; Annor F.O, Renewable and Sustainable Energy Reviews 15 (2011) 5143– 5154

Ministry of Energy. Energy for Poverty Reduction Action Plan for Ghana. A targeted approach to delivery of modern energy services to the poor. Accra, Ghana: (2006) Ministry of Energy.

NDPC. Implementation of the growth and poverty reduction strategy 2006–2009, annual progress report. Accra, Ghana: National Development Planning Commission; 2007.

Network Planner, 2013. http://networkplanner.modilabs.org/docs/

Oteng-Adjeng J., (2012), Meet the Press "Energy For A Better Ghana" Press Release.

Prasad G. Energy sector reform, energy transitions and the poor in Africa. Energy Policy 2008; 36:2806–11.

Sackey T. Why the power shortage? Ing Brew-Hammond A, Kemausuor F, editors. Energy crisis in Ghana: drought, technology or policy? Kumasi: University Press; 2007. p. 6–16.

UNDP Ghana. Liquefied petroleum gas (LPG) substitution for wood fuel in Ghana opportunities and challenges. Accra: 2004, UNDP Ghana.

UNDP. World energy assessment: energy and the challenge of sustainability. New York: (2004) United Nations Development Programme.

Weisser D. Costing electricity supply scenarios: a case study of promoting renewable energy technologies on Rodriguez, Mauritius. Renew Energy 2004; 29(8):1319–47.

World Bank. Ghana accelerating growth to halve poverty; 2009. Available at http://www.worldbank.org/ida. Accessed 2009.

APPENDIX

Appendix A: Output Graphs from the Network Planner

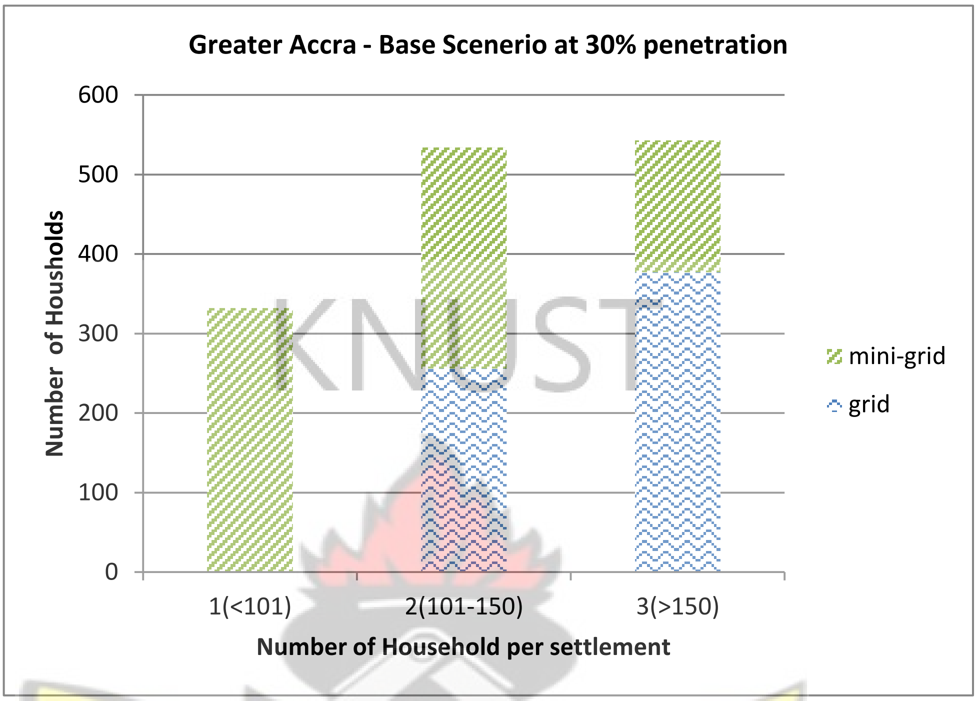

Fig a: Graph showing classification into Number of Households per settlement per technology for Greater Accra Region with the Base Scenario at 30% penetration rate

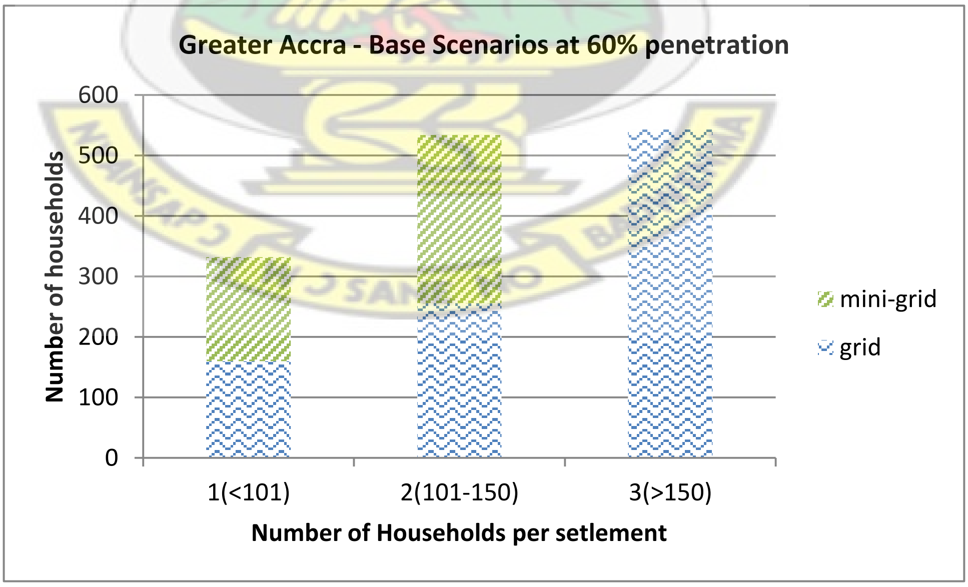

Fig b: Graph showing classification into Number of Households per settlement per technology for Greater Accra Region with the Base Scenario at 60% penetration rate

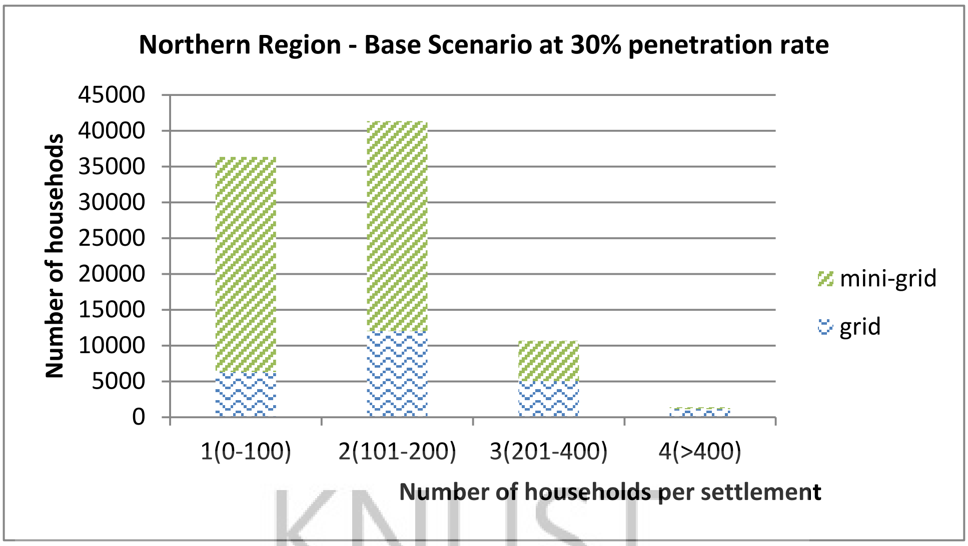

Fig c: Graph showing classification into Number of Households per settlement per technology for Northern Region with the Base Scenario at 30% penetration rate

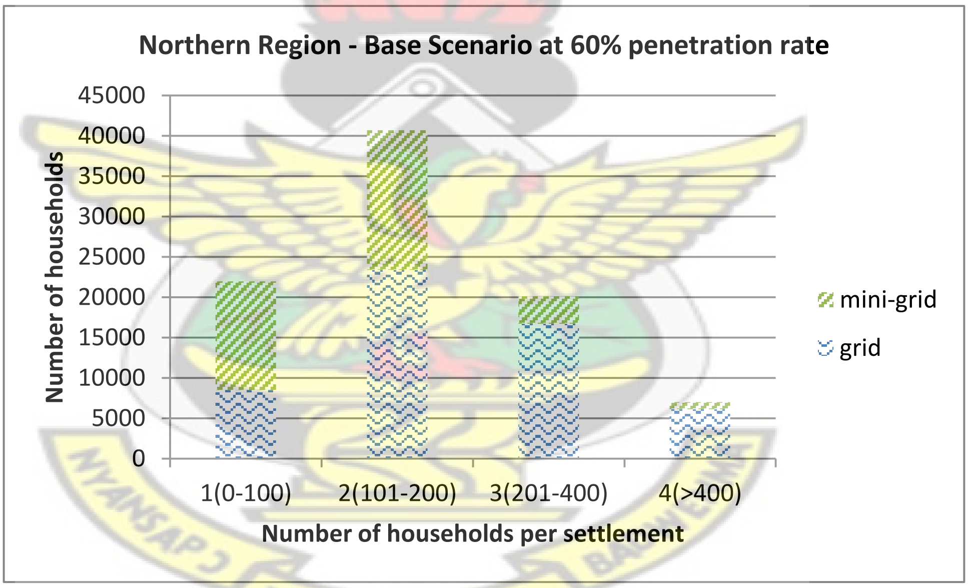

Fig d: Graph showing classification into Number of Households per settlement per technology for Northern Region with the Base Scenario at 60% penetration rate

Appendix B: Default Parameters Used In Modeling

SOCIO-ECONOMIC DATA	Details	Unit	Parameter 2010	Parameter 2012	Sources
FINANCING PARAMETERS					
Time Horizon	Time horizon in years	(years)	10	10	
Interest Rate per year	Yearly interest rate	Dimensionless	0.1157	0.15	BOG
Economic Growth Rate per year		Dimensionless	0.064	0.082	BOG
Elasticity of Electricity Demand		Dimensionless	0.018	1.8	ECG
DEMOGRAPHICS PARAMETERS					
Mean Household Size (Rural)	mean household size (rural)	(persons)	5.4	5.4	
Mean Household Size (Urban)	mean household size (urban)	(persons)	4.7	4.7	
Urban Population Threshold	rural urban threshold	(persons)	5000	5000	GSS
Mean Inter-household Distance	mean inter-household distance in meters	(meters)	25	25	Consultation with experts
Population Growth Rate per year (Rural)	Yearly growth rate (under People)	Dimensionless	0.005	0.005	UN Statistical Division
Population Growth Rate per year (Urban)	Yearly growth rate (under People)	Dimensionless	0.035	0.035	UN Statistical Division
HOUSEHOLD DEMAND					
Base Household Unit Demand per Household	Unit demand in kilowatts per year	(kWh/yr)	150	150	Based on consultation with experts and computation of available data
PRODUCTIVE DEMAND					
Base Productive Unit Demand (per Household)	Unit demand in kilowatts per year	(kWh/yr)	19.5	19.5	

SOCIAL INFRASTRUCTURE DEMAND					
Base Health Unit Demand (per Health Facility)	Unit demand in kilowatts per year	(kWh/yr)	1000	1000	
Base Education Unit Demand (per Education Facility)	Unit demand in kilowatts per year	(kWh/yr)	1200	2000	
Base Commercial Unit Demand (per Commercial Facility)	Unit demand in kilowatts per year	(kWh/yr)	250	350	
Base Public Lighting Unit Demand	Unit demand in kilowatts per year	(kWh/yr)	102	102	
PEAK DEMAND					
Fraction of total demand during peak hours (rural)	fraction of total demand during peak hours (rural)	Dimensionless	0.4	0.4	
Fraction of total demand during peak hours (urban)	fraction of total demand during peak hours (urban)	Dimensionless	0.4	0.4	
Annual peak usage hours	peak electrical usage hours per year	(hrs/yr)	1460	1460	

COST DATA	Details	Units	Parameter		Sources
			2010	**2012**	
SYSTEMS COST PARAMETERS					
Off-Grid: Photovoltaic Systems + Stand-Alone Diesel Generators					
Photovoltaic Systems					
Available Panel System Sizes	system sizes	(kW)	4wp	4wp	Based on consultation with experts and computation of available data
Panel cost per system kilowatt	panel cost per system kilowatt	(US$/kW)	4000	4000	
Balance of System cost factor (as fraction of Panel cost)	balance cost as fraction of panel cost	Dimensionless	0.5	0.5	
Battery energy per system kilowatt	battery kilowatt-hours per system kilowatt	(kWh/kW)	4.5	4.5	

Battery cost per kilowatt-hour	battery cost per kilowatt-hour	(US$/kWh)	125	125	
Photovoltaic Systems Replacement					
Panel lifetime	panel lifetime in years	(years)	20	20	
Balance of System lifetime	balance lifetime in years	(years)	10	10	
Battery lifetime	battery lifetime in years	(years)	5	5	
Operation and Maintenance (O&M)					
O&M Photovoltaic Systems cost factor (as fraction of total Panel System cost)	operations and maintenance cost as fraction of system cost	Dimensionless	0.05	0.05	

COST DATA	**Details**	**Units**	**Parameter**		**Sources**
			2010	**2012**	
MINI-GRID: DIESEL GENERATORS					
Diesel Generators					
Available Diesel Generator System Sizes Standard units for diesel generator system sizes are represented in kW; kW=kVA*Power Factor	system sizes	(kW)	1000.0 750.0 500.0 400.0 200.0 150.0 100.0 70.0 32.0 19.0 12.0 6.0	1000.0 750.0 500.0 400.0 200.0 150.0 100.0 70.0 32.0 19.0 12.0 6.0	
Diesel Generator cost per kilowatt	engine cost per kilowatt	(US$/kW)	441.76	441.76	Based on consultation with experts and computation of available data
Diesel Generator Installation cost factor (as fraction of Diesel Generator cost)	engine installation cost as fraction of engine cost		0.25	0.25	
Diesel Generator Replacement					
Diesel Generator lifetime	engine lifetime in years	(years)	5	5	
Fuel					
Fuel cost per litre	fuel cost per litre	(US$/L)	1.02	1.1	
Fuel litres consumed per	fuel litres consumed per	(L/kWh)	0.5	0.5	

kilowatt-hour	kilowatt-hour				
Operation and Maintenance (O&M)					
Total hours diesel generator is in operation in a year	fuel hours per year	(h/yr)	2190	2190	
Diesel Generator O&M cost factor (as fraction of Diesel Generator cost)	operations and maintenance cost as fraction of engine cost	Dimensionless	0.05	0.05	

MINI-GRID & GRID: Low Voltage Distribution Network	**Details**	**Units**	**Parameter**		**Sources**
			2010	**2012**	
Low Voltage Lines					
Low Voltage Line cost per meter	low voltage line lifetime in years	(US$/m)	US$ 12 and US$ 17	US$ 12 and US$ 17	NED, EC
Low Voltage Lines Replacement					
Low Voltage Line Lifetime	low voltage line lifetime in years	(years)	20	20	NED
GRID: Transformers + Household & Social Infrastructure Connections + Extension					
Electricity cost per kilowatt-hour	electricity cost per kilowatt-hour	(US$/kWh)	0.12	0.22	EC, NED,ECG
Transmission and distribution loss factor (as fraction of grid system demand)	Distribution loss as fraction of system demand	Dimensionless	0.198	0.198	EC, NED,ECG
GRID: Transformers					
Transformer in Low Voltage Network					
Available transformer system sizes (kVA)	system sizes	kW	5 15 20 30 40 50 60 70 80 90 100 200 300 400 500 600 700 800 900 1000	5 15 20 30 40 50 60 70 80 90 100 200 300 400 500 600 700 800 900 1000	
Transformer cost per kilowatt	transformer cost per kilowatt	(US$/kW)	152	152	Based on computation of available

					data
Transformer Replacement					
Transformer lifetime	transformer lifetime in years	(years)	20	20	
Operation and Maintenance (O&M)					
Transformer O&M cost factor (as fraction of Transformer cost)	transformer operations and maintenance cost as fraction of transformer cost	Dimensionless	0.03	0.03	

GRID: Household & Social Infrastructure Connections	**Details**	**Units**	**Parameter**		**Sources**
			2010	**2012**	
Connections to Low Voltage Network					
Equipment cost per connection	equipment cost per household (Up to 40 meters distance)	(US$/HH)	249.7	249.7	Calculation based on MOE data
Installation cost per connection	installation cost per household	(US$/HH)	70	70	NED
Equipment O&M cost factor (as fraction of Equipment cost)	equipment operations and maintenance cost as fraction of equipment cost	Dimensionless	0.01	0.01	
GRID: Medium Voltage Extension					
Medium Voltage Lines					
Medium Voltage Line cost per meter	material and labour cost in dollars per meter of grid extension	(US$/m)	25	25	NED
Medium Voltage Lines Replacement					
Medium Voltage Line Lifetime	lifetime in years	(years)	30	30	NED